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STATE INSPECTION OF AUTOMOBILES TO MONITOR THE PERFORMANCE OF EXHAUST GAS EMISSION CONTROL SYSTEMS

A THESIS

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STATE INSPECTION OF AUTOMOBILES TO MONITOR THE PERFORMANCE OF EXHAUST GAS EMISSION CONTROL SYSTEMS

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SUMMARY

The objective of this research is the design and evaluation of a system to inspect automotive exhaust gas emission control devices. Evidence indicates that reductions in pollutants can be achieved if automobiles receive proper engine maintenance and pollution control devices are functioning properly. The specific question faced by state and local pollution control agencies is what will be the long range cost and effectiveness of a system designed to monitor exhaust gas emissions. This investigation was aimed at (1) developing a procedure to provide inspection system cost-effectiveness information and (2) demonstrating the procedure utilizing best available data. To illustrate the procedure, the five county Atlanta Metropolitan area was chosen.

To accomplish the research objective, a "building block" approach was employed. This approach allows the system to be evaluated by investigation of the relationship of individual components of the system to the total system. Overall estimates are minimized and emphasis is placed upon obtaining measures of the individual components of the system.

The approach taken in this research required development of two computer models: a cost evaluation model and an effectiveness evaluation model. The cost model generates cost and performance data for various inspection system configurations. Total waiting time required for an inspection is used as a measure of the inspection system performance.

The effectiveness model provides year-by-year total pollutant emission data for three pollutants (carbon monoxide, hydrocarbons and nitrogen oxides). This data includes total expected emissions, total reduction in emissions expected from implementation of the inspection system and an effectiveness measure indicating the percentage of potential reductions expected to be realized. In calculating this data, deterioration of automotive pollution control devices is an important factor considered in the effectiveness model. Both the cost and the effectiveness models are designed to provide data for inspecting vehicles at either an annual or a biannual frequency.

The investigation illustrated the need for systematic analysis and planning to manage air resources for a metropolitan area. As a result of this investigation cost-effectiveness data concerning state inspection of automobiles have been obtained. Several recommendations for further research in this area are provided.

CHAPTER I

INTRODUCTION

In many air basins of the United States, there exist no mechanism to ensure that automotive pollution control systems are properly maintained. The Federal government can establish pollution standards applicable to *new* motor vehicles and engines. Also, the Federal government can perform certification testing to monitor the performance of prototype vehicles and engines. However, to date, Federal authority ends when the new motor vehicle or engine is sold to the public. For this reason, action on the state level of government may be required to guarantee that automotive pollution control systems are performing properly under actual operating conditions.

The general objective of this research is to design and evaluate a system to inspect automotive exhaust gas emission control devices. Investigation of state inspection of automobiles provides additional information to air resource managers faced with evaluating various abatement strategies to control automotive pollution. To illustrate the investigation approach and to provide useful information, the investigation is based upon providing an inspection system for the five county Metropolitan Atlanta, Georgia area.

Based upon interviews with the Georgia air pollution control agency, a decision was made that the inspection system should be designed to perform three functions:

1. Determine the exhaust emissions of carbon monoxide, hydrocarbons and nitrogen oxides,
2. Determine whether the emission control system is performing properly,
3. Prescribe a remedy if emissions exceed standards.

Successful performance of the three functions is the goal established for the inspection system. Factors such as the frequency of inspection, the type of test equipment utilized, and the total customer waiting time are important design considerations of this investigation.

The evaluation portion of the investigation considers the cost and effectiveness of state inspection of automobiles to reduce air pollution. Some of the cost items are investment cost in test equipment and facilities. Also, the operating cost (fixed and variable) and the breakeven cost per vehicle are estimated. Effectiveness of state inspection is measured in terms of estimated quantities of pollutant emissions and reductions achieved.

Information received from California and New Jersey provided data concerning pollutant reductions achieved through inspection along with data indicating the rate of deterioration of exhaust pollution control systems resulting from actual, on-the-road driving conditions. Cost data, such as labor cost, are representative of the Atlanta Metropolitan area.

Utilizing existing data and proposed Federal automotive pollutant standards, this investigation evaluates important design and evaluation aspects of state inspection of automobiles to reduce air pollution. The order of presentation of this investigation is as follows:

1. Chapter II covers a review of the literature to define progress in automotive pollution control and to identify promising abatement strategies available to state governments.

2. Chapter III discusses the method of approach utilized in this investigation.

3. Chapter IV describes and presents the assumptions, procedures, and details of the effectiveness evaluation methodology. Data acquisition is also discussed.

4. Chapter V presents the details of the cost evaluation methodology. Inspection system design assumptions are presented and discussed. Also, total customer waiting time at the inspection facilities is discussed. Data utilized in making cost and waiting time estimates are provided.

5. Chapter VI gives cost and effectiveness results of annual and biannual inspection between 1975 and 1985 in the Atlanta Metropolitan area. Also, sensitivity analyses are performed.

6. Chapter VII presents conclusions and recommendations.

CHAPTER II

LITERATURE SURVEY

Introduction

The problem of air pollution has existed for centuries. As early as the fourteenth century public dissatisfaction with atmospheric pollution is noted by historians [26, p.9]. Until around 1945, emphasis was placed upon control of stationary sources of air pollution with control of sulfur-bearing fossil fuel combustion attracting the most attention. In the early forties a new type of pollution made its appearance in Los Angeles, which had become highly industrialized and heavily populated during World War II [29]. After several years of intensified programs to control stationary sources of sulfur dioxide and hydrocarbon emissions in Los Angeles, laboratory experiments indicated that gasoline powered mobile combustion sources were contributing significantly to the air pollution problem.

Since the forties several approaches pertaining to controlling air pollution from mobile sources have been implemented or are being investigated. These approaches are summarized in Table 1. Air pollution literature reviewed during this investigation relates only to the first option listed in Table 1, emissions level reductions at the source.

The first section of this chapter reviews the historical development of automotive pollution control from 1959 to the present.

Table 1. Summary of Options for Controlling Pollution from Mobile Sources

1.	Emission level reductions at the source.
2.	Improved road design to reduce traffic congestion.
3.	Decrease the use of vehicles through mass transportation.
4.	Replace gasoline powered mobile sources with other vehicular propulsion systems.

The purpose of this section is twofold:

1. To show the trend in motor vehicle emission control.
2. To define the Federal and state roles in controlling pollution from vehicles.

The remaining portion of the chapter deals with the problem of identifying promising inspection procedures that are feasible for local pollution control agencies.

Historical Development of Automotive Pollution Control

From 1959 to 1971, intensified efforts to control automotive air pollution have occurred on both the Federal and state level of government. California pioneered the initial efforts to control automotive air pollution. It was not until 1965 that strong Federal legislation was passed to attack the automotive problem on a national basis.

In 1959, the California State Board of Public Health was directed ". . . to submit by February 1, 1960, maximum allowable standards of emissions of exhaust contaminants from the motor vehicles . . ." [29, p.28]. Standards were established for exhaust carbon monoxide and hydrocarbons. By late 1960, California had adopted a standard for crankcase emissions of hydrocarbons. U. S. automotive manufacturers began voluntarily to equip 1961 automobiles sold in California with crankcase emission control devices. By 1963 all new automobiles sold nationwide were equipped to control crankcase emissions for hydrocarbons. The crankcase emission control devices virtually eliminated emissions emanating from the crankcases [40].

In the early sixties, California also developed a procedure to test exhaust emission control devices. The test was based upon a seven mode driving cycle. Emission control devices were originally required to operate satisfactorily for 12,000 miles [11, p.3-1]. In 1965, revisions were made to require devices to operate satisfactorily for 50,000 miles.

Other efforts by California to control automotive pollution include:

1. Certifications of compliance for vehicles in certain counties,
2. Tickets given by the California State Highway Patrol for vehicles emitting excessive visible smoke,
3. A random spot-check system incorporated into the safety inspection system.

The Federal effort from 1960 until 1965 consisted of studying the problem to determine if a nationwide effort was required [29, 9]. Also, the Federal government recommended research approaches and evaluated the merits of pollution control devices [29].

In 1965, the Clean Air Act of 1963 was amended to give the Secretary of Health, Education and Welfare power to set air pollution standards for new vehicles.

> The Secretary shall by regulation, giving appropriate consideration to technological feasibility and economic costs, prescribe as soon as practicable standards, applicable to the emission of any kind of substance, from any class or classes of new motor vehicles or new motor vehicle engines [28].

The Secretary of Health, Education and Welfare not only set standards, but also was required to perform certification testing of the control devices. In 1966, Federal standards were set for crankcase emissions and exhaust emissions of carbon monoxide and hydrocarbons. The standards applied to 1968 model year light-duty vehicles (vehicles less than 6001 pounds gross weight).

In 1967, Congress passed the Air Quality Act of 1967, an amendment to the Clean Air Act of 1963. Under this law, states were prohibited from setting standards for new motor vehicles. The law did, however, allow provisions which in essence allowed California to have stricter standards than ones applicable to vehicles sold on a nationwide basis.

The Air Quality Act of 1967 provides for Federal assistance to states for the development of vehicle inspection programs. Grants were authorized ". . . in an amount up to two-thirds of the cost of developing meaningful uniform motor vehicle emission device inspection and emission testing programs" [1]. Two provisions must be satisfied to receive the grant:

> (1) No grant shall be made for any part of any State vehicle inspection program which does not directly relate to the cost of air pollution aspects of such a program; and (2) No such grant shall be made unless the Secretary of Transportation has certified to the Secretary that such program is consistent with any highway safety program developed pursuant to section 402 of title 23 of the United States Code [1].

The Air Quality Act of 1967 also provides that

> Nothing in this title shall preclude or deny to any State or political subdivision thereof the right otherwise to control, regulate, or restrict the use, operation, or movement of registered or licensed motor vehicles [1].

From 1967 to 1970, efforts were made to develop standardized test procedures for measuring quantities of pollutants emitted from mobile sources. Measured pollutants could then be compared to the established standards. Procedures for testing for compliance have been published [15,16]. These procedures were later modified. Because of the changes in test procedures, data collected on a given test procedure is not easily compared to data gathered on a modified test procedure. The most recent procedures for testing for compliance are based upon an allowable grams per mile per vehicle [21]. Earlier standards were expressed in pollutant concentrations, such as parts per million (ppm). Testing for compliance with Federal standards is not performed on each motor vehicle. Vehicle manufacturers are required to provide representative vehicles to the Federal government for compliance testing.

In 1970, Congress passed the "Clean Air Amendments of 1970" [10]. Although numerical standards are not given, the Act does indicate the intent of the Federal government to establish strict future emission standards for light-duty vehicles. Given 1970 model year vehicles as a base level, a 90 per cent reduction in carbon monoxide and hydrocarbons emissions will be required for light-duty vehicles and engines manufactured during or after model year 1975. Also, for nitrogen oxides a 90 per cent reduction from the base level will be required for vehicles manufactured in or after 1976. The base level for nitrogen oxides is 1971 model year vehicles.

The Clean Air Amendments of 1970 also provide that if reliable methods and procedures can be developed to test vehicles in actual use, the vehicle manufacturers will be required to guarantee the emission control device or system for new light-duty vehicles beginning one year after testing methods are established. This warranty would last for 50,000 miles and the cost to repair the emission control device would be borne by the manufacturer.

Review of the literature from 1959 to the present indicates that state inspection of automobiles is seriously being considered as an option for controlling pollution from mobile sources. Three important conclusions concerning a state's role in controlling pollution from motor vehicles are drawn:

1. State governments cannot set emission standards for new motor vehicles (excluding California).

2. State governments do have the right to require that devices be maintained.

3. Federal grants are authorized (within provisions defined by law) for developing meaningful motor vehicle emission device inspection and emission testing programs.

Inspection Procedures

A report to the National Air Pollution Control Administration gives five possible inspection procedures for state vehicle emission inspection [37]. The procedures and a brief description of each are given in Table 2. The literature reviewed herein concentrates upon the last two procedures: emission measurements at idle and emission measurements on a short cycle.

The first procedure in Table 2 was omitted because study results indicate reductions in pollutant emissions would be very low [13]. The second and third procedures were eliminated because reports indicate that future control techniques by vehicle manufacturers will employ add-on equipment whose performance is not a function of engine tune-up [41]. For instance, exhaust gas recirculation and catalytic mufflers are anticipated control devices for future vehicles.

In a study by M. F. Chew presented in 1969, some correlation is shown which indicates that high carbon monoxide and hydrocarbon emitters at idle conditions are high emitters at other modes of operation [5]. Table 3, based on the study by Chew, represents results for vehicles *without* control devices. Results for vehicles *with* control devices are given in Table 4. Another study by M. F. Chew concerned with inspecting vehicles to identify high emitters of oxides of nitrogen shows a very weak correlation between emissions at idle versus emission results at other modes of vehicle operation [6].

Information from literature published by the Federal government concerning exhaust measurement at idle, however, indicates limited

Table 2. Inspection Procedures for State Vehicle Emission Inspection

1.	Visual Inspection	Inspect to see that required control devices are present and intact; check for rough idle and unusual sounds from engine or exhaust system; check exhaust smoke density. Reject if defects observed.
2.	Engine Tune-up Check	Check idle RPM, idle air-fuel mixture, ignition timing and other important engine parameters. Reject if parameters out of manufacturer's specifications.
3.	Mandatory Tune-up	Perform minor tune-up consisting of adjusting idle RPM, idle air-fuel mixture, ignition timing and other engine parameters to manufacturer's specifications. Reject is parameters cannot be brought into specification limits.
4.	Emission Measurement at Idle	Measure exhaust HC, CO, NO_x, opacity, and perhaps crankcase pressure or HC emissions at idle (and/or possibly at some higher RPM). Reject if emissions are above established standards.
5.	Emission Measurement Short Cycle	Measure exhaust HC, CO, NO_x, opacity and perhaps crankcase pressure or HC emissions while vehicle is driven through a predetermined short cycle on a dynamometer. Reject if emissions are above established standards.

diagnostic ability. "Although an idle test may indicate which vehicles have abnormally high emissions, it provides very little diagnostic aid as to what specific type of malfunction or maladjustment produces the high emissions" [11, p.4-9]. This last quote could be significant since emission control systems are becoming more sophisticated. Also, one should note that ". . . many engines that are not well tuned may perform

Table 3. Correct Identification and Errors for Vehicles *Without* Control Devices (California Auto Club Data, 1961-1963)

	Low Emitters (Number of Vehicles)	High Emitters (Number of Vehicles)
Total	543	496
Identified	418	354
Errors	125 commission	142 omission
Identified, %	77	71

Low Emitters: HC < 770 ppm, CO < 4.0%
(at idle)

High Emitters: HC ≥ 770 ppm, CO ≥ 4.0%
(at idle)

Table 4. Correct Identification and Errors for Vehicles *with* Control Devices (AMA-CMVPCB Data, 1966)

	Low Emitters (Number of Vehicles)	High Emitters (Number of Vehicles)
Total	67	27
Identified	53	19
Errors	14 commission	8 omission
Identified, %	80	70

Low Emitters: HC < 400 ppm, CO < 2.5%
(at idle)

High Emitters: HC ≥ 400 ppm, CO ≥ 2.5%
(at idle)

adequately at idle, but poorly under load" [11, p.4-9]. Public acceptance of a system limited to idle inspection only is therefore questionable.

Emission inspection on a short cycle test is another alternative available to states. Basically, a short cycle test simulates actual driving conditions to get representative emission data. (One will remember that the Federal government's test cycle to certify new motor vehicles also simulates driving conditions. However, complexity, time requirements, and cost of equipment make it unacceptable for implementation on the state level of government to test vehicles in use.) The short cycle inspection utilizes a dynamometer which would, therefore, make equipment cost and operating costs higher than costs associated with the idle test procedure.

Several short cycle tests are available. A comparison of five short cycle tests is given in a report by Ethyl Corporation [14]. A portion of the comparison of short cycle tests by Ethyl Corporation is given in Table 5.

Based upon the results of the short-cycle test, a vehicle owner would have diagnostic information to make necessary repairs. Not only would repairs result in reduced emissions, but also four other benefits could be derived from proper maintenance: improved fuel economy, improved reliability, better performance, and improved engine life [33]. Benefits may offset the costs of repairs. The short cycle test is chosen for this investigation since it offers a promising diagnostic test procedure which is available to local air pollution control agencies. As stated in Chapter I, an important function of the inspection system is that it provide diagnostic information to enable the vehicle owner to repair malfunctioning emission control systems.

Table 5. Comparison of Short Cycle Tests

Test	Time Required (Minutes)	Correlation with Federal Cycle	Diagnostic Capability	Equipment Cost
Acid	2-5	Good	Very limited	High
Exit	2-5	Good	Good	Very High
N.Y. Quick	2-5	CO Good HC Poor	Very limited	High, but less than for Acid
Key Mode	2-5	Good	Good	Moderate
Quasi-static	5-10	Poor	Very limited	Low

Discussion of Literature Survey

The literature survey provided assistance in defining the problem by following the chronological events which have led to the present state-of-the-art in automotive pollution control. Developing and evaluating future abatement strategies, however, is very difficult. This is particularly true of designing and evaluating systems to inspect mobile combustion sources. On the one hand, the literature indicates that stringent Federal standards will reduce emissions from new vehicles. On the other hand, the public is demanding improvements in air resources. Figure 1 illustrates the problem.

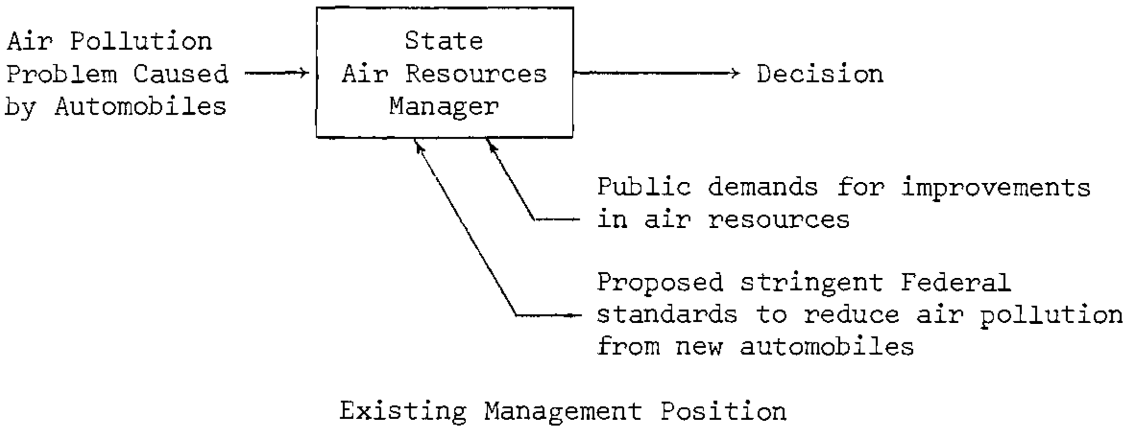


Figure 1. Existing Decision Making Position of a State Air Resources Manager

Since decisions based on partial knowledge must be made, it behooves air resources managers to try to investigate the sensitivity of a decision to the assumptions used in making the decision. It is the purpose of this investigation to provide new insights relative to this problem. Specifically, the cost-effectiveness of a system to inspect automobiles will be investigated. Figure 2 illustrates the basic approach of this investigation and the improved management information which results from this investigation.

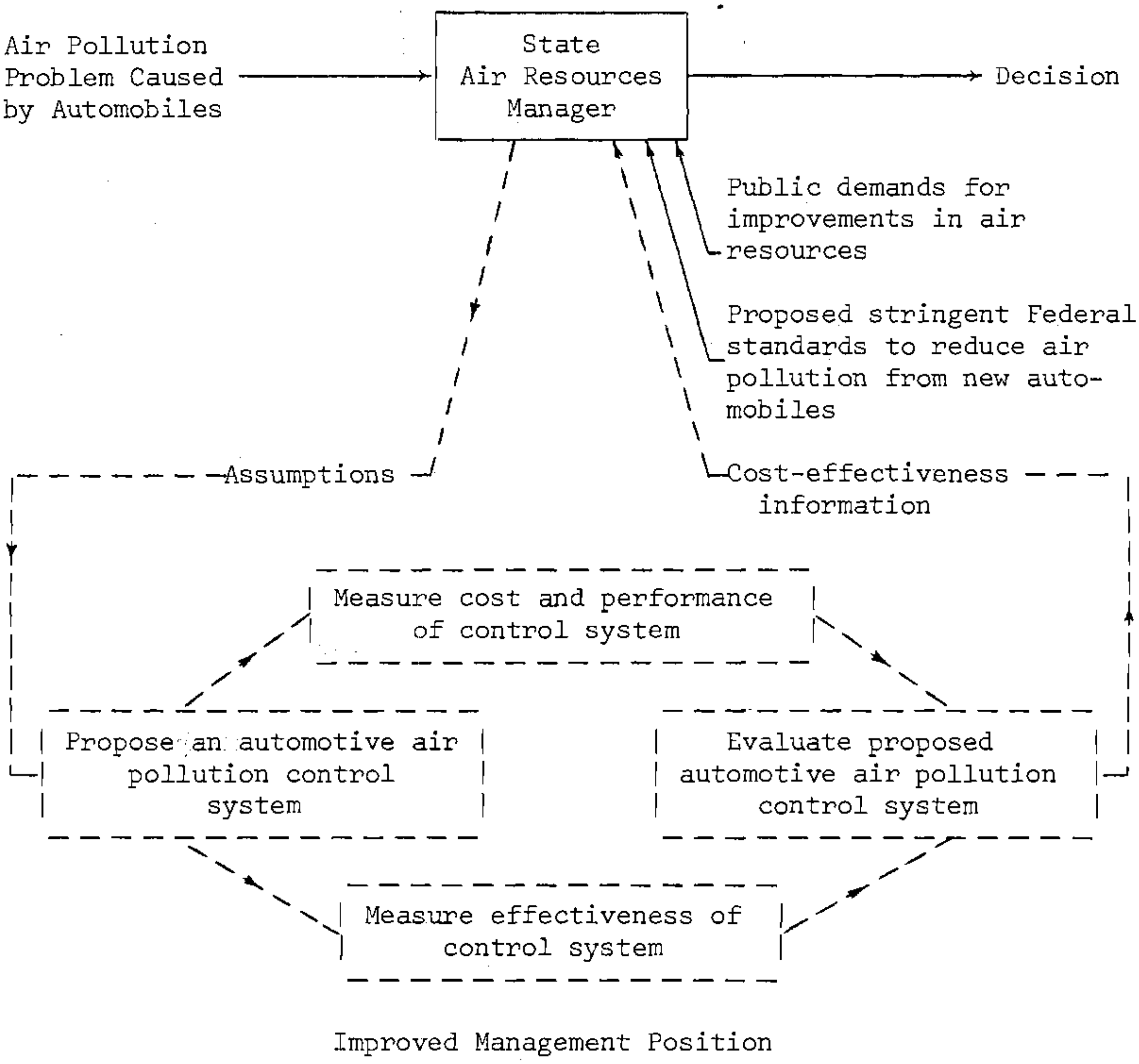


Figure 2. Improved Decision Making Position of an Air Resources Manager

CHAPTER III

METHOD OF APPROACH

The development of an approach to evaluate the cost and effectiveness of state inspection of automobiles was a primary consideration in this research. The approach should be developed in a manner allowing air resource managers to utilize the approach to estimate cost and effectiveness data based upon several policy decision alternatives. For example, to simplify the vehicle inspection procedure, an air resource manager may choose to enforce only one carbon monoxide exhaust standard applicable to all vehicles. Other air resource managers may want to specify individual hydrocarbon exhaust standards for each vehicle model year.

Realizing the need for flexibility in developing an approach to evaluate the cost and effectiveness of state inspection of automobiles, a "building block" approach was employed. The building block approach constructs the system to be evaluated in a manner allowing investigation of the relationship of individual components of the system to the total system. In this manner, emphasis is placed upon obtaining measures of the individual components of the system.

Steps of Investigation

After the basic approach to accomplish the research objective had been finalized, the research proceeds as described in the following steps:

1. The specific problem to be investigated is defined (Chapter III).

2. Limitations of the study are established (Chapter III).

3. Measures of effectiveness needed to evaluate state inspection of automobiles are defined (Chapter IV).

4. A computer model, denoted Pollution Control Model (PCM), is developed to estimate the effectiveness measures (Chapter IV).

5. Data inputs and policy decisions (i.e., state standards) needed to demonstrate PCM are obtained (Chapter IV).

6. Cost and performance measurements required to evaluate the feasibility of state inspection are defined (Chapter V).

7. A computer model, denoted Cost Model (CM), is developed to estimate measurements of cost and performance for various inspection system configurations (Chapter V).

8. To demonstrate CM, required input data is obtained (Chapter V).

9. Cost and effectiveness results of inspection system behavior between 1975 and 1985 are presented and discussed (Chapter VI).

10. Cost and effectiveness sensitivity analysis is performed and discussed (Chapter VI).

11. Conclusions and recommendations are given (Chapter VII).

Statement of the Problem

The problem faced in this research is to design and evaluate a system to inspect automotive exhaust gas emissions control devices. A cost effectiveness procedure is used to evaluate the inspection system.

Cost effectiveness is measured as cost per ton of pollutant reduced by the proposed inspection system.

A characteristic of an inspection system is its configuration. Inspection system configurations proposed for this investigation are:

1. All one lane inspection facilities.
2. All two lane inspection facilities.
3. All three lane inspection facilities.
4. All four lane inspection facilities.
5. All five lane inspection facilities.

Since only inspection on a short cycle test is considered, the effectiveness of the inspection system is independent of its specific configuration. That is, one would get the same total pollutant reduction if one chose to implement all one lane inspection facilities or all five lane inspection facilities. However, the *cost per ton of pollutant reduced* is variable and is directly dependent upon the specific inspection system configuration chosen.

Criteria used to evaluate the proposed inspection system configurations are:

1. Number of facilities required
2. Investment costs
    a. Equipment
    b. Facilities
3. Annual Costs
    a. Capital Recovery plus interest
    b. Labor (fixed and variable)

c. Electricity, gas, maintenance and supplies

d. Breakeven cost per vehicle inspected

4. Average time (waiting time plus servicing time) per vehicle at the inspection facility.

Limitations of the Study

The geographical area for this research is the five county Metropolitan Atlanta area. Figure 3 gives the region size of the study. The five counties comprise a standard metropolitan statistical area and have been designated by the Federal government as an air quality control region. One should be aware that the region size of a study concerned with mobile sources need not be based upon the same approach employed in this research. Consider Figure 4. In certain northeastern states the population density may justify statewide inspection. On the other hand, in certain western states with large counties and population densities concentrated around one city, another approach may be justified.

Three pollutants are considered in this investigation; they are carbon monoxide, hydrocarbons and oxides of nitrogen. These pollutants contribute to the majority of problems associated with mobile sources.

Passenger cars and light-duty trucks, which together comprise the bulk of the vehicle population, are the only category of mobile combustion sources considered. Heavy duty gasoline powered vehicles and diesels are omitted. The total number of heavy duty gasoline trucks is small compared to the total number of passenger cars and light-duty trucks. Also, their pollutant contribution to the system under consideration

GEORGIA– STANDARD METROPOLITAN STATISTICAL AREAS, COUNTIES, AND PLACES OF 10,000 OR MORE

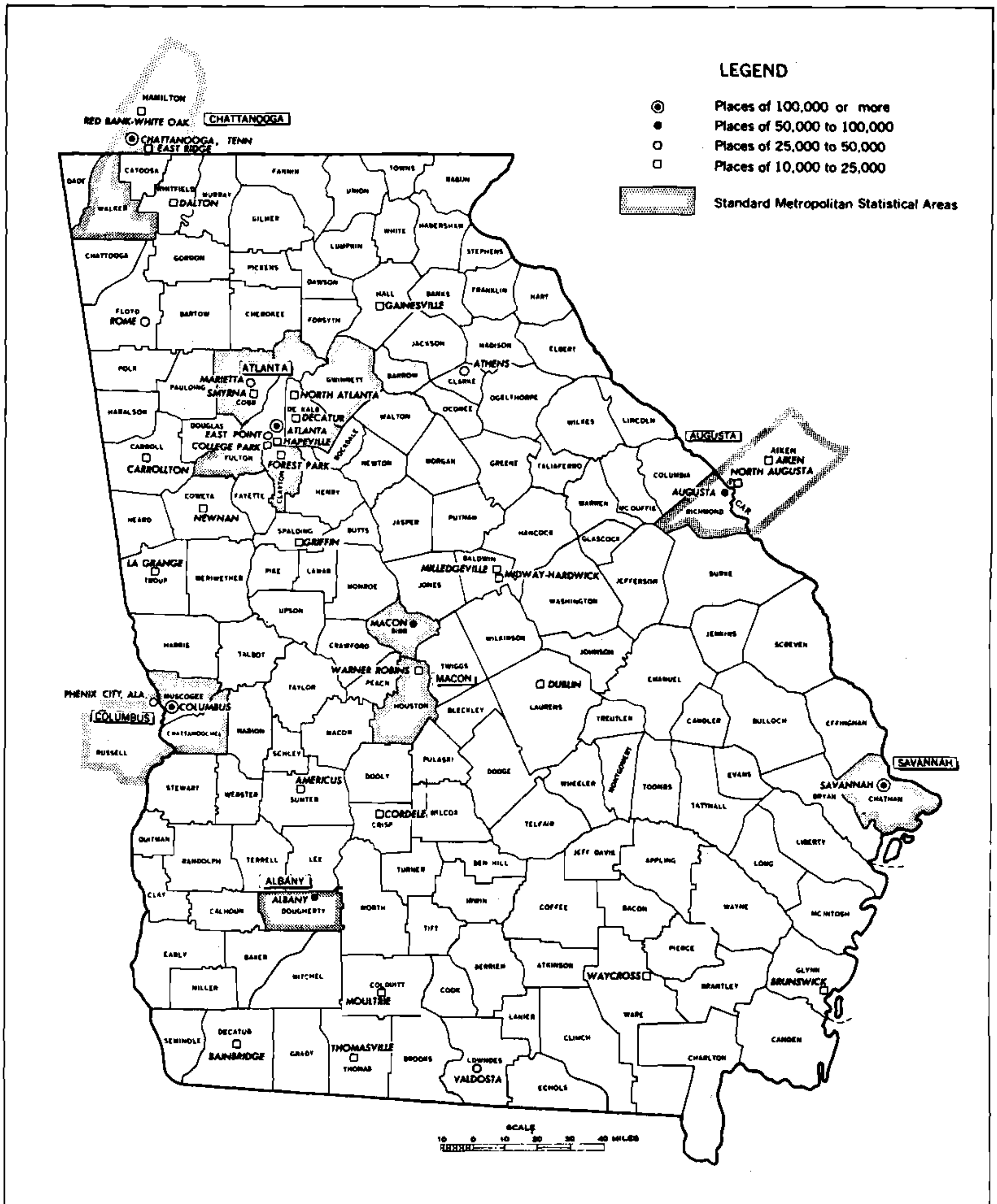


Figure 3. Standard Metropolitan Statistical Areas in Georgia [Reference 4]

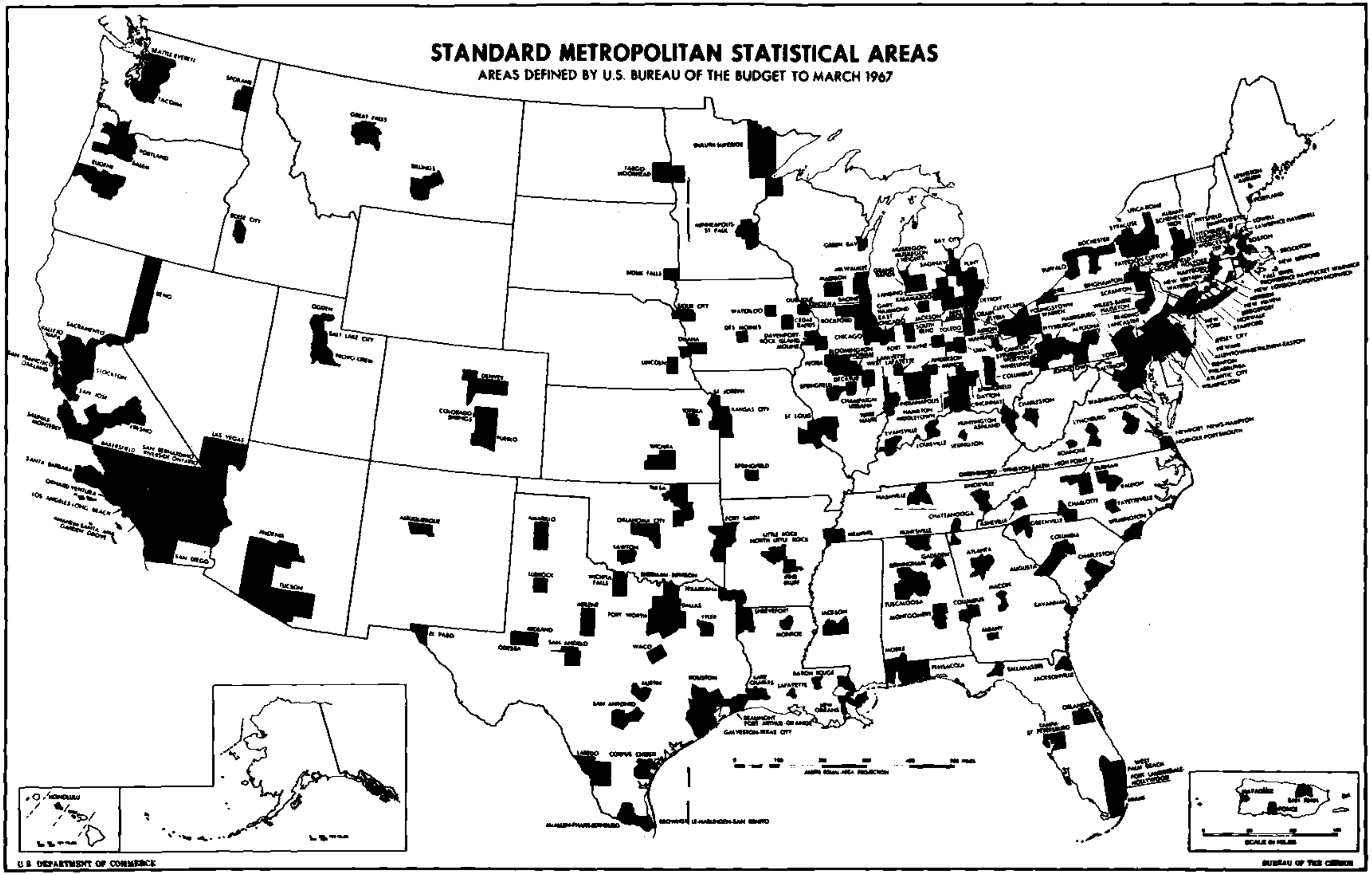


Figure 4. Standard Metropolitan Statistical Areas in the United States [Reference 39]

is questionable since many are long-distance oriented as opposed to driving in urban areas. Diesel powered vehicles are omitted for two reasons. First, anticipated federal standards for diesels are concerned with smoke density, that is, particulate matter emitted. The pollutants considered in this study do not include particulates. Second, the total number of diesel as compared to gasoline powered vehicles is small. It is reasonable to assume diesels could be added to the inspection system without significantly affecting the design of the system. Omission of heavy duty gasoline powered vehicles and diesels is also justified because they would significantly complicate an understanding of this investigation. For instance, different standards are applied to heavy duty gasoline powered vehicles as opposed to light-duty gasoline powered vehicles manufactured in the *same* year.

The time span evaluated in the study was 1975-1985. The projections are not made beyond 1985 because of the uncertainty of several assumptions made in the model. For instance, travel distribution by age of vehicle is assumed to be the same in 1975-1985 as it has been in the recent past. Because of rapid transit or changes in population locations, travel distributions could easily change making the model inappropriate for years beyond 1985. Economic evaluation of the inspection system is simplified by purchasing test equipment for carbon monoxide, hydrocarbons, and oxides of nitrogen all in the same year.

Emission quantities are expressed in tons per year. A finer time resolution is not believed to change the significance of the results. Also, conversion of pollutant tons per year to ambient pollutant concentrations is not considered. Diffusion models are available to perform the conversion [27,35]. Given that year to year meteorological and topographical conditions are similar, the approach taken here does permit one to examine trends in air pollutant emissions and to anticipate an increase or a decrease in existing air quality levels.

One should be cautioned of two pitfalls in expressing the emissions in tons per year. First, a ton of carbon monoxide is not necessarily as harmful as a ton of hydrocarbon. However, these pollutants could be weighted according to toxicity to indicate a health hazzard associated with each pollutant. Second, since the numerical measurement of the exhaust gas pollutants depends upon the inspection test procedure employed, one must use care to express and compare emissions all relative to the same test procedure. This is done in this investigation.

Cost information reported in the Investigation Results (Chapter VI) includes only the cost that would be incurred by the state, and these costs are calculated on a per car basis. Discounts for high volume purchases or state and local sales taxes are not included. Annual cost items, such as electricity, are typical of the Atlanta area. Cost to the public associated with time and expense required in driving to and from the inspection facility are not included. No cost representing lost time associated with waiting time is considered in this investigation. Also, cost of repairing pollution control devices is not included.

The inspection facilities are assumed to operate eight hours per day, 250 days per year. Facilities operating two eight-hour shifts per day are not considered. Annual and biannual inspection is also considered.

CHAPTER IV

MEASURES OF EFFECTIVENESS

This chapter describes the procedure that was developed in this investigation to predict annual emissions of carbon monoxide, hydrocarbons and nitrogen oxides generated by light-duty mobile combustion sources. Because the calculations of each of the pollutants are similar, the discussion in this chapter is confined to a single pollutant, carbon monoxide.

In the first sections of this chapter, the types of measures needed and the assumptions required to evaluate the effectiveness of state inspection of automobiles are given. Next, the methods developed to estimate the effectiveness measures are presented. Details of the estimation methodology, utilizing the Atlanta metropolitan area as an example application, are given.

Types of Measures

The types of measures used to evaluate the effectiveness of state inspection of automobiles should be quantitative. Also, measures should relate to overall goals of air pollution control programs concerned with medical, aesthetic and economic effects of air pollution. Recognizing there are limitations in predicting ambient air quality levels resulting from implementation of an inspection system, the following three measures of effectiveness were chosen:

1. Percentage of uncontrolled level emitted with inspection.

2. Total estimated reductions in tons per year.

3. Percentage of potential reductions achieved by inspection.

The first measure indicates the total pollutant emissions with state inspection relative to the total pollutant emissions without state inspection. The second measure estimates the absolute reductions achieved by state inspection. Pollutant reductions as presented in this study could be weighted to indicate economic, health and aesthetic effects associated with each pollutant. The third measure gives the effectiveness of state inspection in terms of what it can realistically provide.

Assumptions

After deciding upon the effectiveness measures to be employed in this investigation, several assumptions were required to approximate the real world behavior of an inspection system. A discussion of these assumptions is now given.

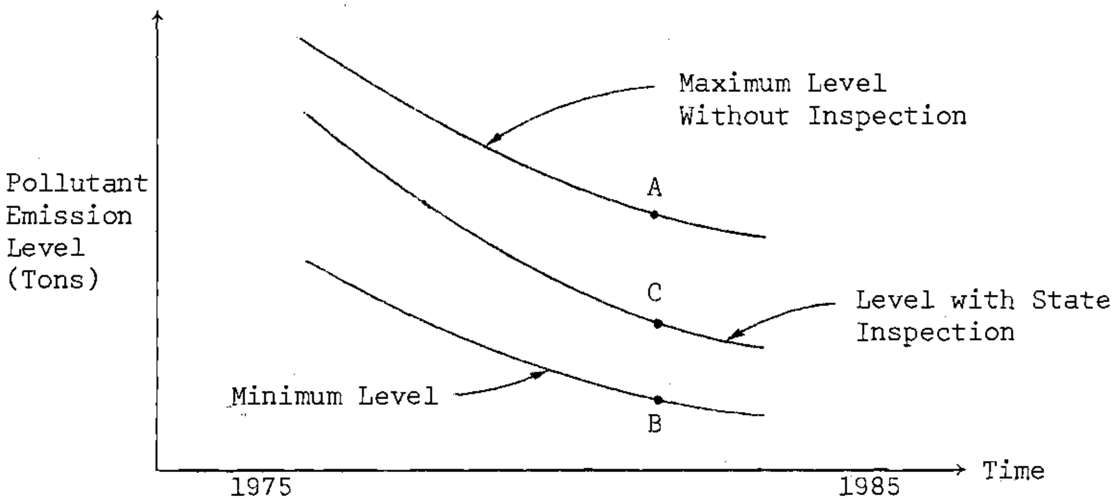
Total Pollutant Emissions Profile

To obtain an estimate of the measures of effectiveness chosen for this investigation, three estimates of pollutant emissions are required:

1. Emissions without implementation of the inspection system (an upper limit).

2. Emissions with implementation of the inspection system.

3. Minimum emissions with implementation of the system (a lower limit).



The emission level profiles that are the basis for calculating the effectiveness of an automotive inspection system are presented above. The upper profile (Maximum Level Without Inspection) represents the annual emissions expected if there is no inspection of automobiles and the emission control devices deteriorate at a typical rate.

The lower profile (Minimum Level) represents the annual emissions expected if the emission control devices do not deteriorate, thus remaining as effective as when they were originally installed. If this condition exists, the emission control devices would be operating at the existing and proposed Federal standards over the life of the car. This minimum level thus represents an extremely optimistic position with regard to the effectiveness of emission control devices over time under actual operating conditions.

The middle profile (Level with State Inspection) indicates the expected annual emissions if inspection of the emission control devices on automobiles is required. It is assumed that each time an automobile is inspected the owner will be required to remedy the malfunctioning devices so that the automobile emissions will not exceed an amount 10% greater than Federal standards.

Figure 5. Pollutant Emission Level Profiles

The total emissions without the inspection system represent an estimated upper limit on the quantity of pollutants emitted. With an inspection system implemented, the total emissions experienced depend upon the degree of control exerted by the inspection system. If the assumption is made that the degree of control on a vehicle cannot exceed the original design capabilities, a minimum expected quantity of emissions (a lower limit) can be calculated.

Figure 5 defines the three pollutant levels required to estimate the measures of effectiveness. Figure 6 illustrates how the three pollutant levels are used to calculate the measures of effectiveness.

1. Percentage of Maximum Level $= \dfrac{\text{Level with State Inspection}}{\text{Maximum Level without Inspection}}$

$$= \frac{C}{A}\,(100)$$

2. Total Estimated Reductions = Difference between Maximum Level without Inspection and Level with State Inspection

$$= A - C$$

3. Percentage of Potential Reductions Achieved $= \dfrac{\text{Difference between Maximum Level without Inspection and Level with State Inspection}}{\text{Difference between Maximum Level without Inspection and Minimum Level without Inspection}}$

$$= \frac{A - C}{A - B}\,(100)$$

Note: A, B, and C given above refer to levels shown in Figure 5.

Figure 6. Measures of Effectiveness

Initial Implementation of the Inspection System

The first year of inspection system implementation will result in an altered distribution of the vehicle population as measured by pollutant emission rate. Specifically, vehicles above a particular state standard will be required to take corrective action to reduce the amount of pollutants they emit. To allow for the possibility of multiple pollutant standards for vehicles with control devices, the vehicle population is first categorized by vehicle model year. Next, a histogram for each model year vehicle population is constructed. Figure 7 is used to illustrate a histogram for one vehicle model year population near the time of initial implementation of the vehicle inspection system. The cell widths in Figure 7 are expressed in pollutant emission rates. Whenever representative emission rate distribution data is not available for a model year vehicle population, a normal distribution about the average emission rate is assumed.

Increases in Pollutant Emissions Between Successive Inspections

In this study the present vehicle population is categorized into two distinct groups:

1. Vehicles without pollution control systems
   (Pre-1968 vehicles)

2. Vehicles with pollution control systems
   (Post-1967 vehicles)

Reduction in carbon monoxide exhaust pollutants from the first group, vehicles without pollution control systems, can be achieved through conventional engine tune-ups. Engine tune-ups to reduce carbon monoxide, for example, would require carburetor adjustments or possibly replacement

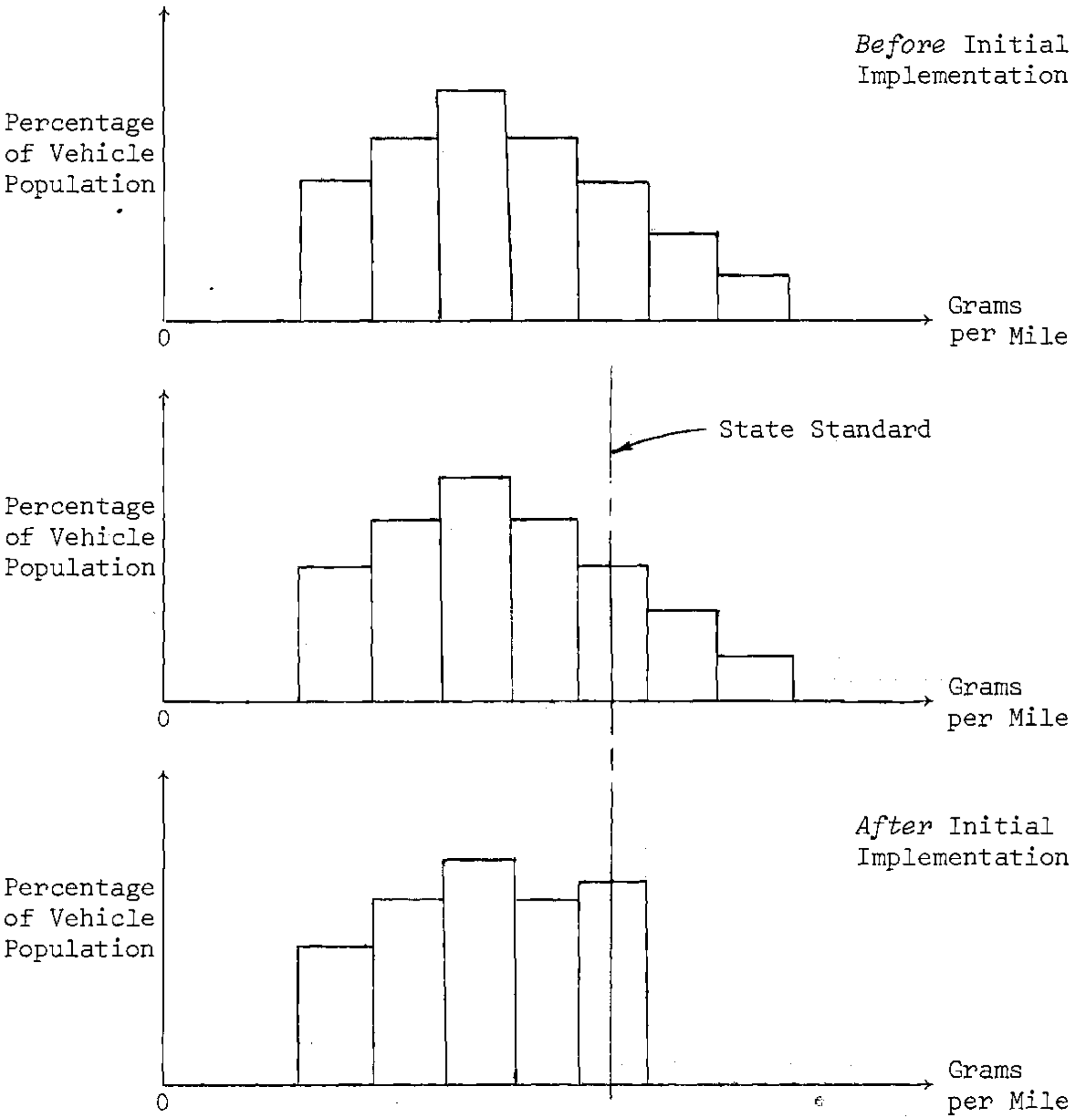


Figure 7. Distribution Emissions by Vehicle Population Near Time of Initial Implementation of Inspection System

of a malfunctioning carburetor. Reduction in exhaust pollutants from the second group, vehicles with pollution control systems, is accomplished in the following ways:

1. Engine tune-up
2. Proper maintenance of pollution control systems.

Pollution control systems, like any other mechanical system, are subject to deterioration. Improper maintenance or owner neglect can cause malfunctions of the pollution control systems. Figure 8 is used to illustrate the effect of deterioration of pollution control systems and vehicles getting out-of-tune between successive inspections.

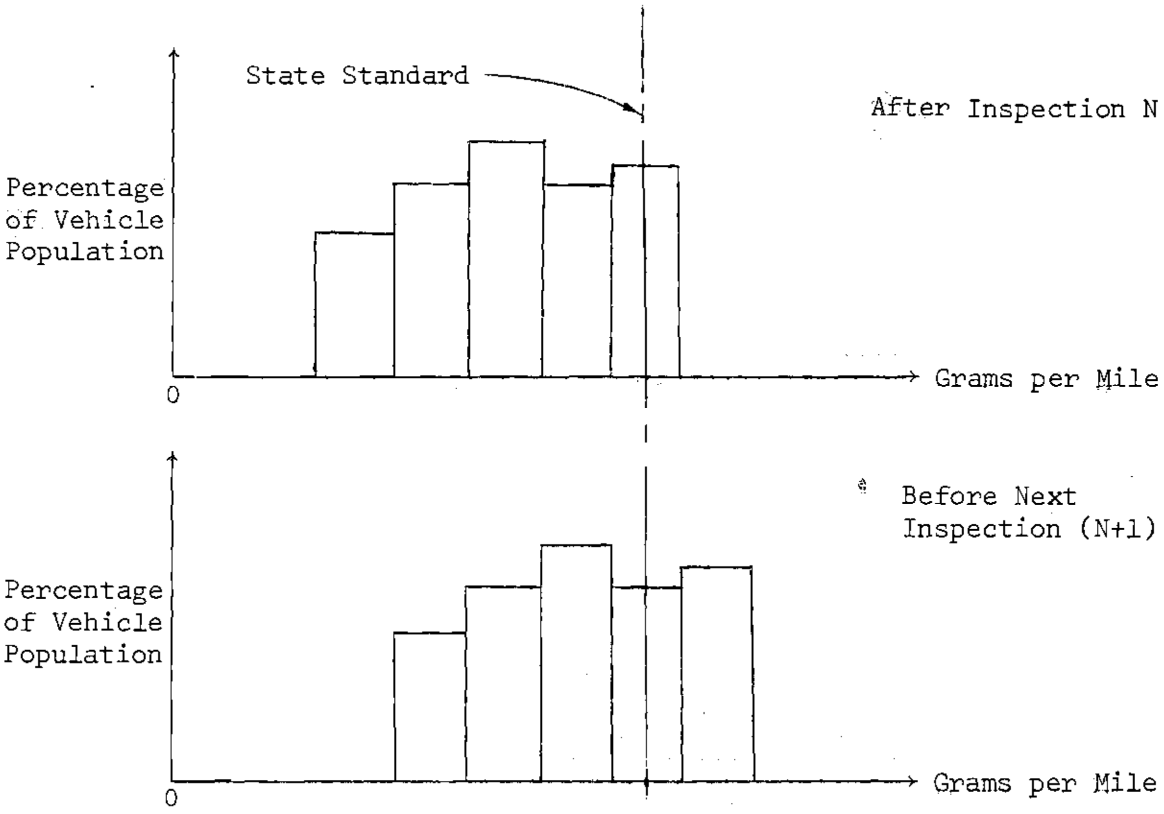


Figure 8. Increases in Pollutant Emissions Between Inspections

The shift in the histogram in Figure 8 represents an increase in the pollutant emission rates between inspections. The cell widths in Figure 8 are expressed in pollutant emission rates. As stated previously in this chapter, histograms for each vehicle model year are required because of the possibility of individual state standards for each vehicle model year.

One will note the general shape of the deterioration curve in Figure 9.

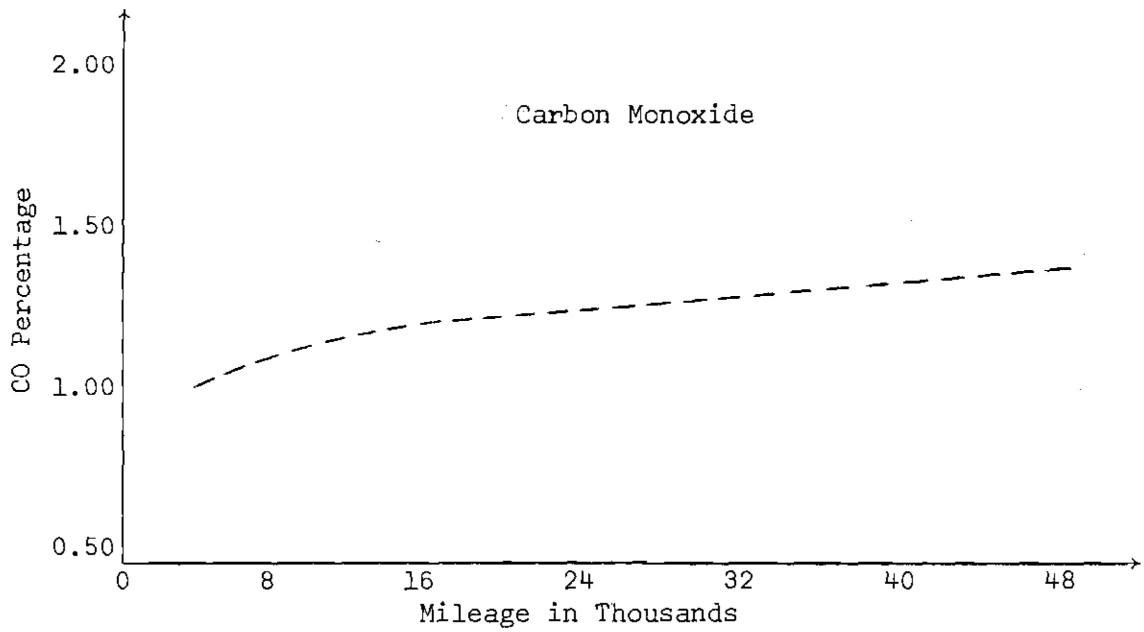


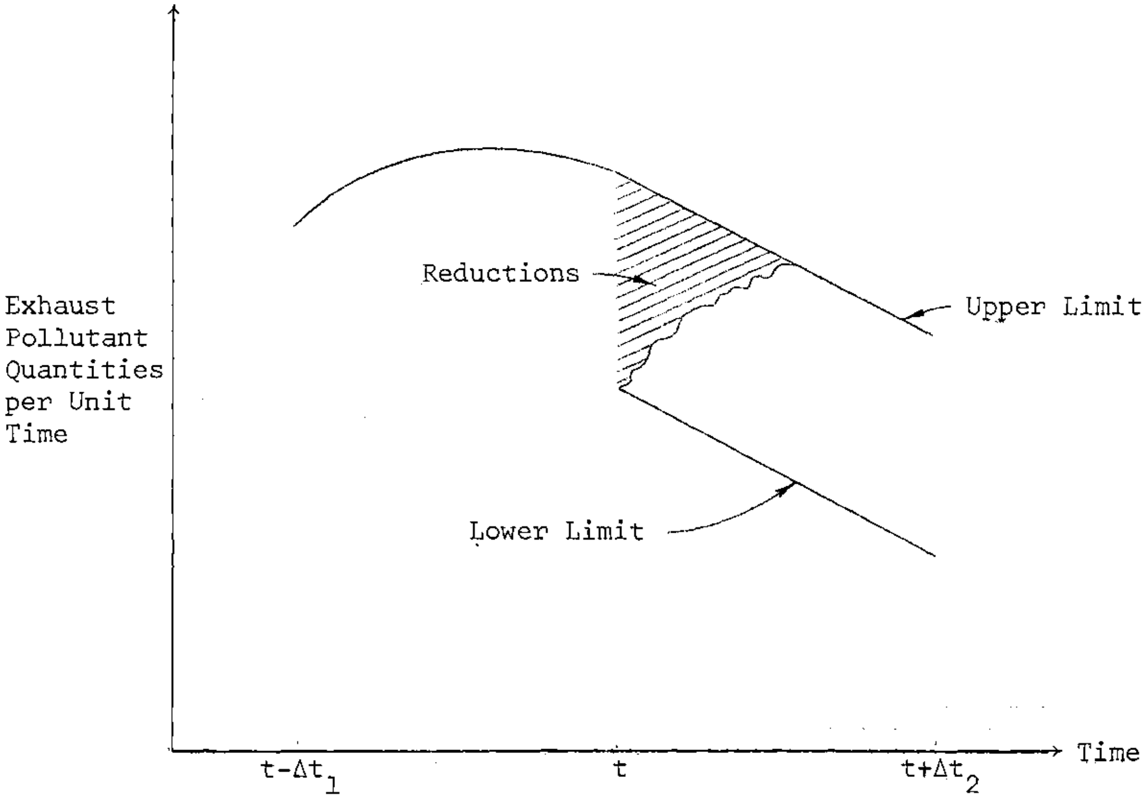
Figure 9. Exhaust Emissions vs. Mileage (1968 Model California Automobiles, Total Population) [Source: Reference [25, p.13]]

Deterioration is more rapid for low cumulative mileage than for high cumulative mileage. The rate of increase appears to be constant above approximately 24,000 miles. A reasonable assumption would be that vehicles which are corrected to meet state standards will deteriorate at a constant rate before the next inspection. This rate will depend upon the slope of the deterioration curve.

For vehicles without control systems (pre-1968 vehicles), a reasonable assumption to use for estimating increases in pollutant emissions between successive inspections is not obvious. It would not be realistic to assume that pre-1968 vehicles which are initially required to tune-up to meet a state standard will remain in tune for the remainder of the vehicle life. To simplify an understanding of the problem, a constant rate of increase between successive inspections is also assumed. Since as time progresses, pre-1968 vehicles represent a decreasing percentage of the total vehicle population and also since pre-1968 vehicles will be driven less than post-1967 vehicles, the assumption of a constant rate of increase in emissions is justified. The assumption applies only to pre-1968 vehicles which are initially above the state standard. For pre-1968 vehicles which were initially below the state standard, it is assumed they are inherently low emitters or that they have owners who will keep them in tune.

Frequency of Inspection

Behavior of the system over the desired time span is difficult to visualize. After the initial implementation of the pollution control system, the problem becomes one of maintaining the desired control. If an inspection system were implemented for a short length of time and then discarded, it is reasonable to believe the vehicle population, at some time in the future, would once again reach the upper limit. Figure 10



where

$t-\Delta t_1$ = point in time before implementation of the pollution control model.

t = time of initial implementation and discarding of the pollution control model.

$t+\Delta t_2$ = point in time after implementation of the pollution control model.

Figure 10. Conceptual Illustration of Implementing a Pollution Control System and Then Discarding the System

illustrates the results of implementing a system, then discarding the system. The influence of the frequency of inspection upon the effectiveness of the system is illustrated in Figure 11.

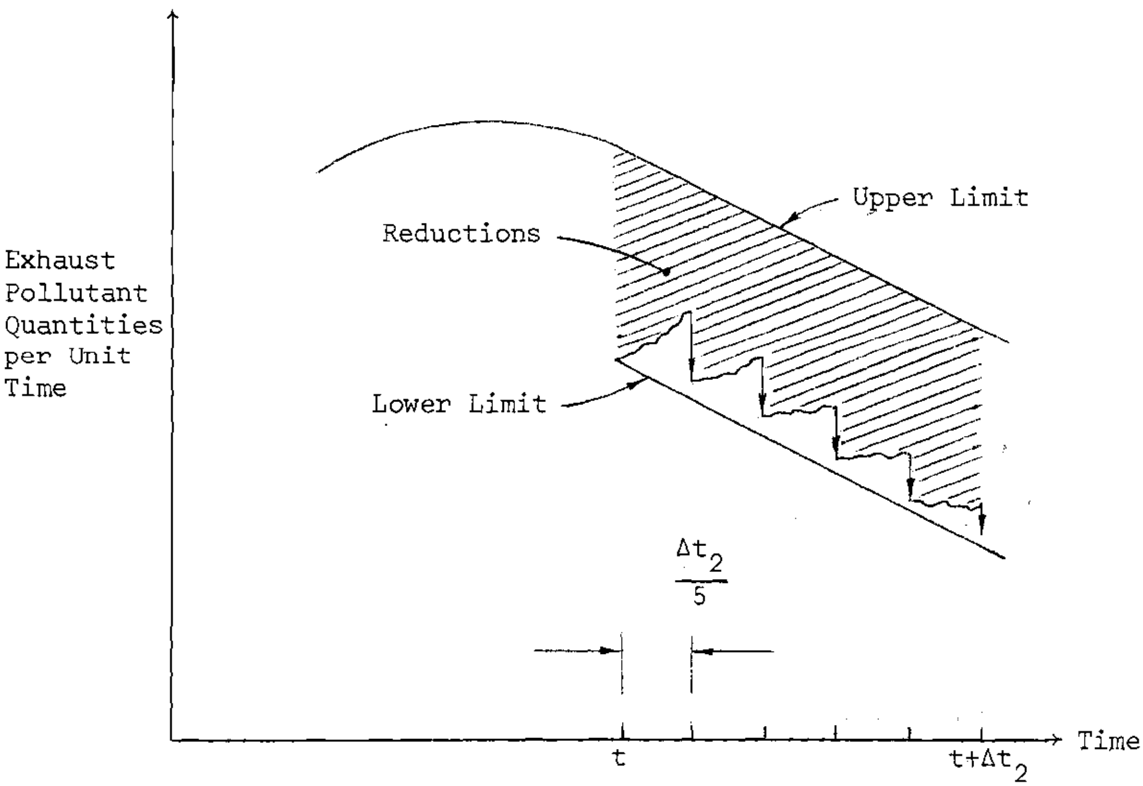


Figure 11. Conceptual Illustration of Inspecting at Frequency $\Delta t_2/5$

In this study, annual and biannual frequency is investigated.

<u>Estimating Pollutant Emissions for Vehicles with Deteriorating Pollution Control Systems</u>

Figure 9 illustrates the effect of deterioration of pollution control systems over 50,000 miles. Estimating the amount of pollution contributed by a vehicle with a deteriorating emission control system over a given time span is also considered. Figure 12 illustrates the problem. If one were estimating a representative emission rate for a vehicle between mileage m and mileage m + Δm, one would not choose point X or point Y. Point X would underestimate the pollution contribution and point Y would overestimate the pollution contribution. A more representative emission rate for the mileage between m and m + Δm would be (X+Y) divided by 2.

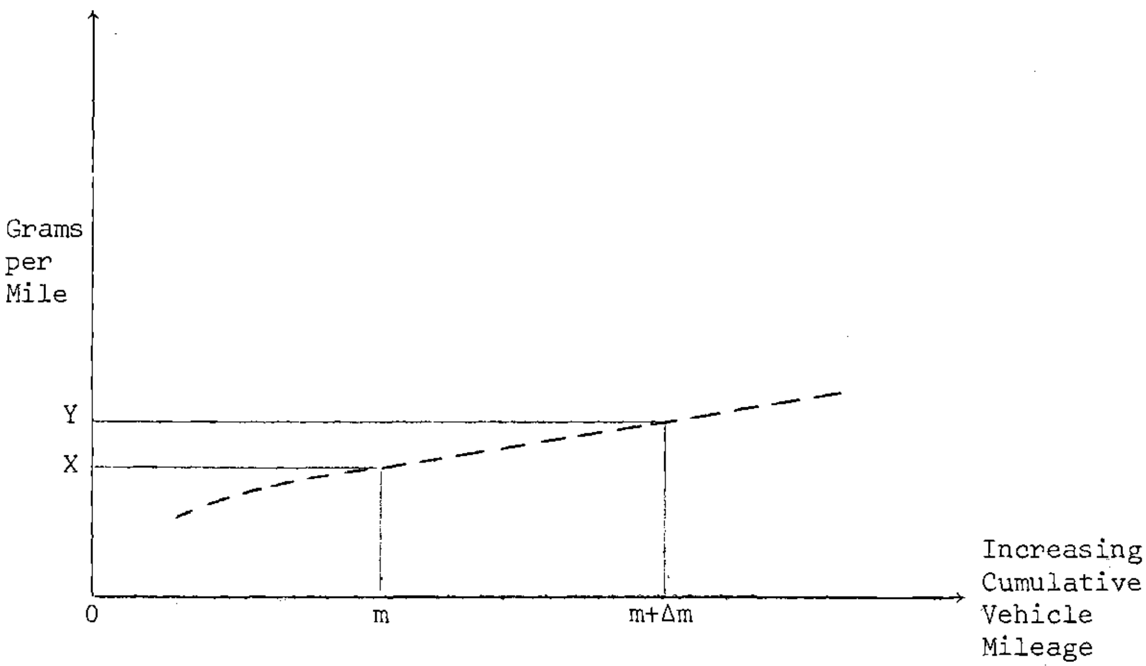


Figure 12. Choosing a Representative Emission Rate for a Vehicle Between m and m+Δm Miles

Using the same argument as presented in the previous paragraph, the behavior of the total vehicle population would operate at a level shown by the dotted line in Figure 13. To justify the last statement consider Figure 14. Suppose all vehicles were corrected on 7/1/74 to emit 30 grams of carbon monoxide per mile. On 7/1/75, the vehicles

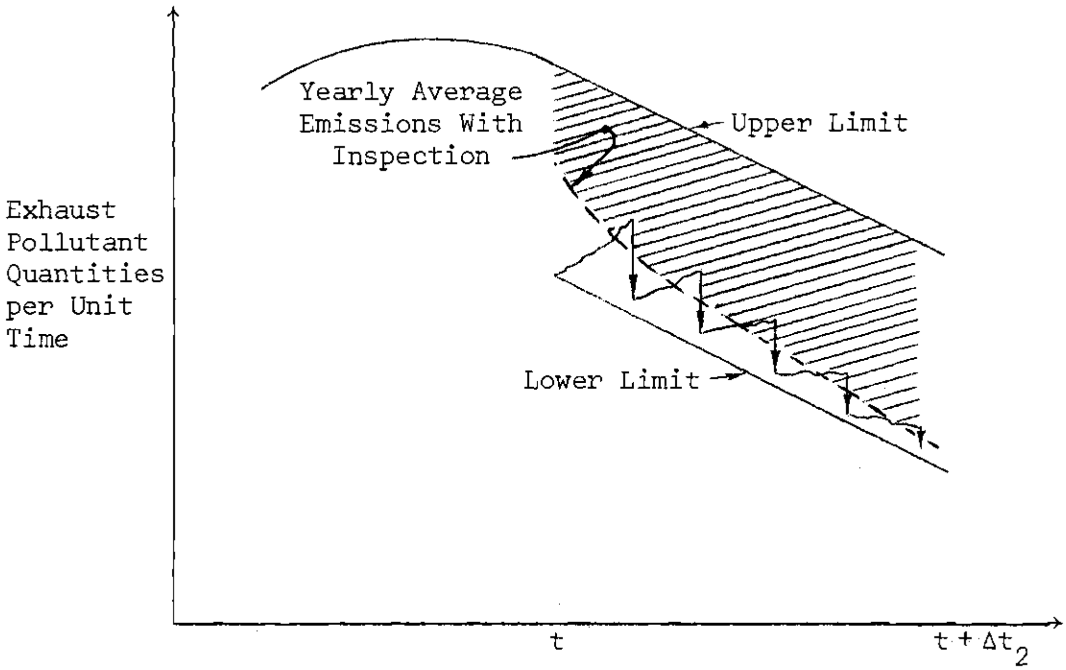


Figure 13. Behavior of Inspection System Between Time t and Time $t + \Delta t_2$

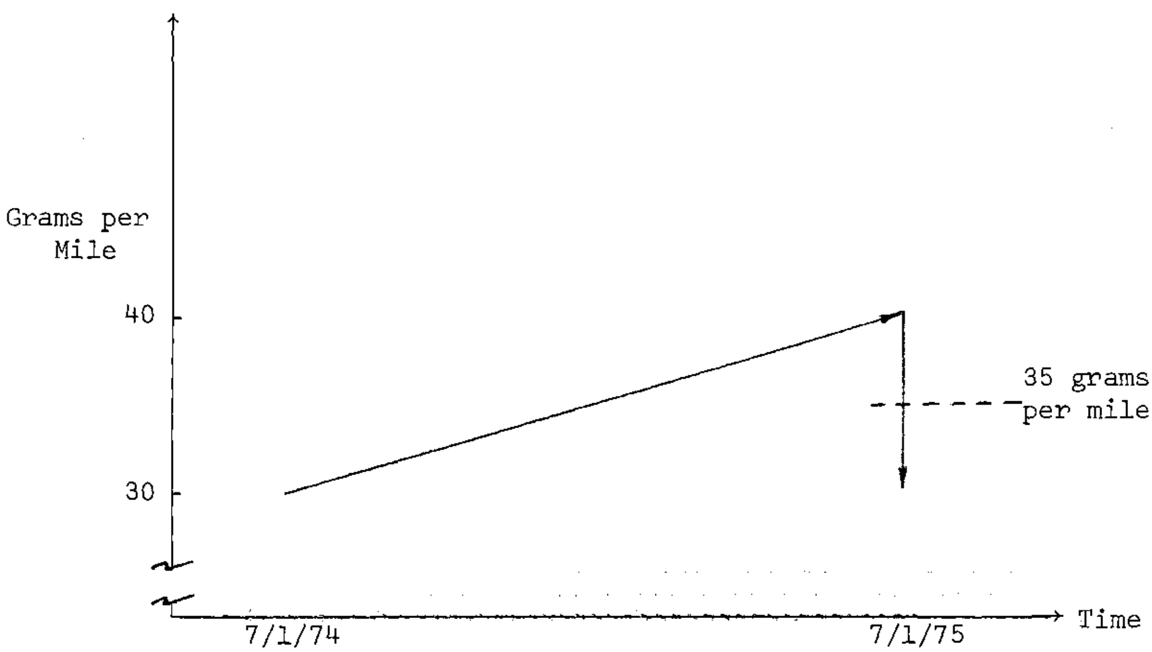


Figure 14. Calculating Representative Pollutant Emissions for the Total Vehicle Population

were inspected and found to be emitting 40 grams of carbon monoxide per mile. A representative emission rate between 7/1/74 and 7/1/75 for the vehicle population would be 35 grams per mile.

Method of Investigation

Since evaluating the effectiveness of an automotive inspection system over a given time span can require numerous calculations, a computer model, denoted Pollution Control Model (PCM), was developed to make the calculations. The PCM is written in Fortran IV. The Georgia Institute of Technology's Univac 1108 was utilized to make the calculations. Calculations for one computer processing requires approximately eight seconds. The overall structure of the PCM is shown in Figure 15.

Details of Evaluation Methodology

The remainder of this chapter discusses the methodology employed in evaluating the effectiveness of inspection for the Atlanta Metropolitan area between 1975 and 1985. The details of the evaluation methodology are described by presenting the PCM as it was developed for investigating the Atlanta Metropolitan area.

The inputs and outputs of the PCM for carbon monoxide calculations are given in Figure 16. Design parameters representing population, ratio of vehicles to population, etc., are inputs to the PCM. The state air pollution control agency has little control over the input design parameters since they are affected by exogenous forces. Design variables such as frequency of inspection represent inputs which the state may require to evaluate policy decisions.

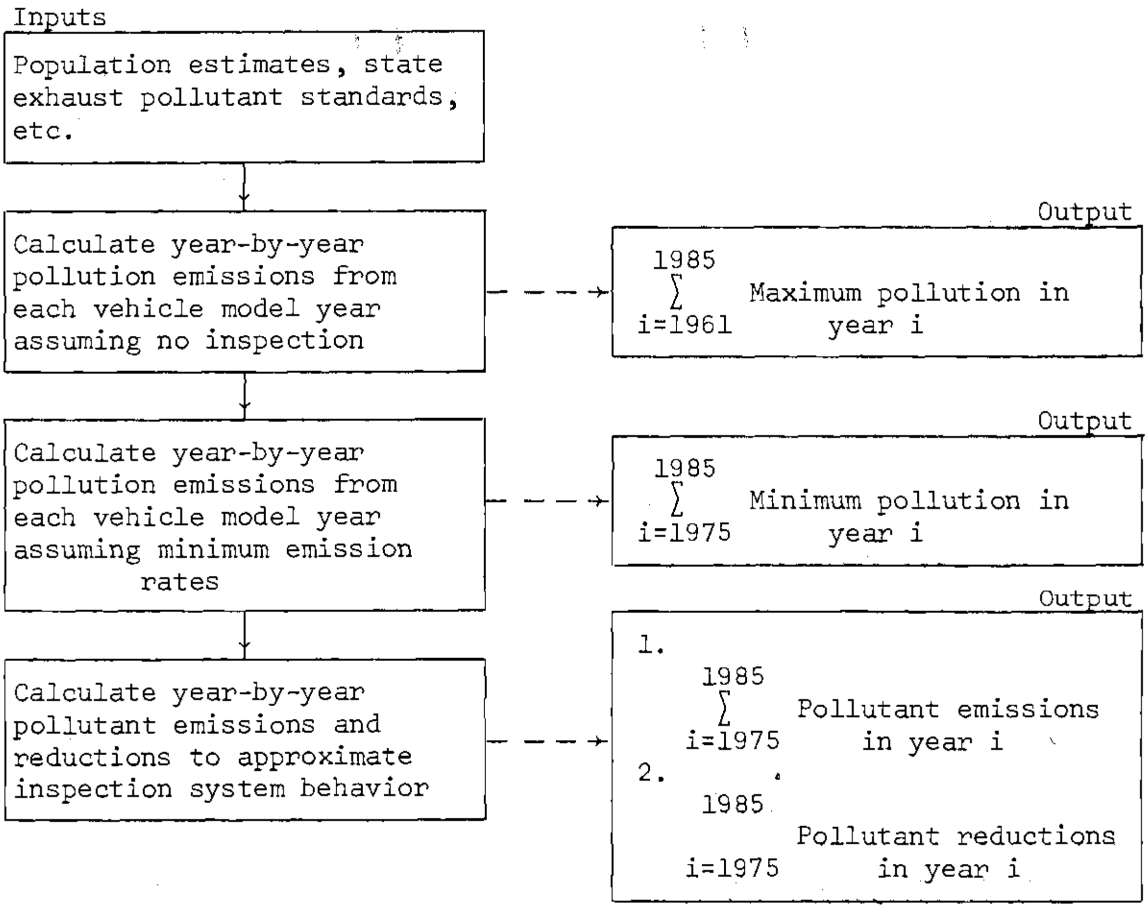


Figure 15. Overall Structure of Pollution Control Model

Four flow diagrams are given in Appendix A to illustrate how the inputs to the PCM are utilized to make the necessary calculations.

Development of the PCM occurred in five basic steps:

Step 1. Calculate the year-by-year total number of vehicles over the time span of interest.

Step 2. For each year, breakdown the total number of vehicles into each vehicle model year population.

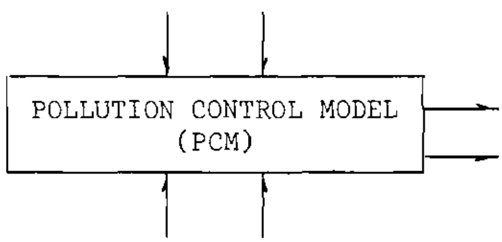
Step 3. Calculate the pollutant emissions assuming no inspection.

Step 4. Calculate the pollutant emissions assuming minimum vehicle emission rates.

Step 5. Calculate the pollutant emissions and reductions to approximate inspection system behavior.

Inputs to the PCM are discussed completely the first time they appear in the development of the PCM. Data values for the required inputs are the ones utilized to investigate the Atlanta Metropolitan Area.

Input Design Parameters
Population
Ratio of Vehicles to Population
Vehicle Probability Age Distribution
Vehicle Probability Mileage Distribution
Uncontrolled Pollutant Emission Rate
Indicator of the Degree of Federal Control
Federal Exhaust Pollutant Standards



Outputs

Max. Pollutant Emissions (1961-1985)

Min. Pollutant Emissions (1975-1985)

Emissions with State Inspection (1975-1985)

Input Design Variables
State Exhaust Pollutant Standards
First Year Inspection System is to be Implemented
Last Year of Study Period
Annual or Biannual Inspection

Figure 16. Inputs and Outputs of the Pollution Control Model (PCM)

Step 1. Total Number of Vehicles

The total number of vehicles for each year of interest is calculated by multiplying the total population by the ratio of vehicles to population in each year. This approach was employed because year-by-year projections of the total number of vehicles were not available.

Population. The trend in population growth for the Metropolitan Atlanta Area is given in Figure 17.

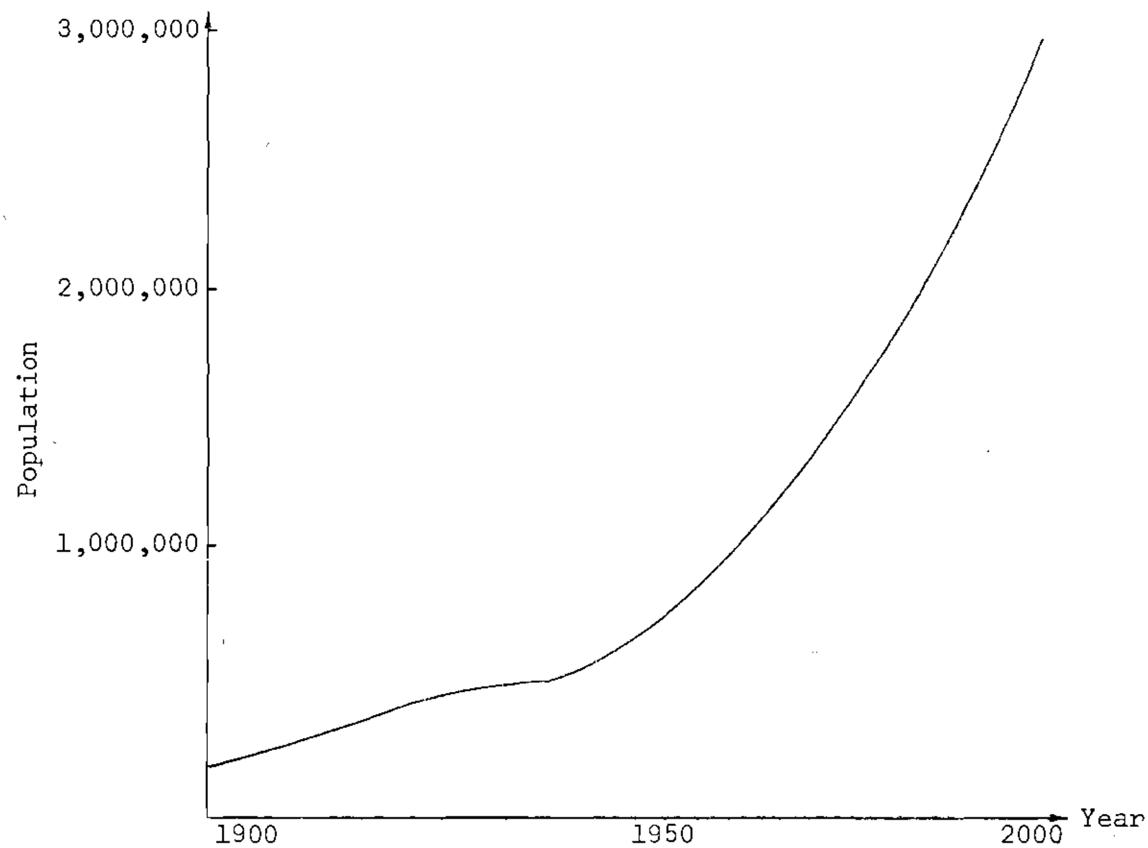


Figure 17. Projected Population, Atlanta Metropolitan Area (1900-2000) [Source: Reference 31.]

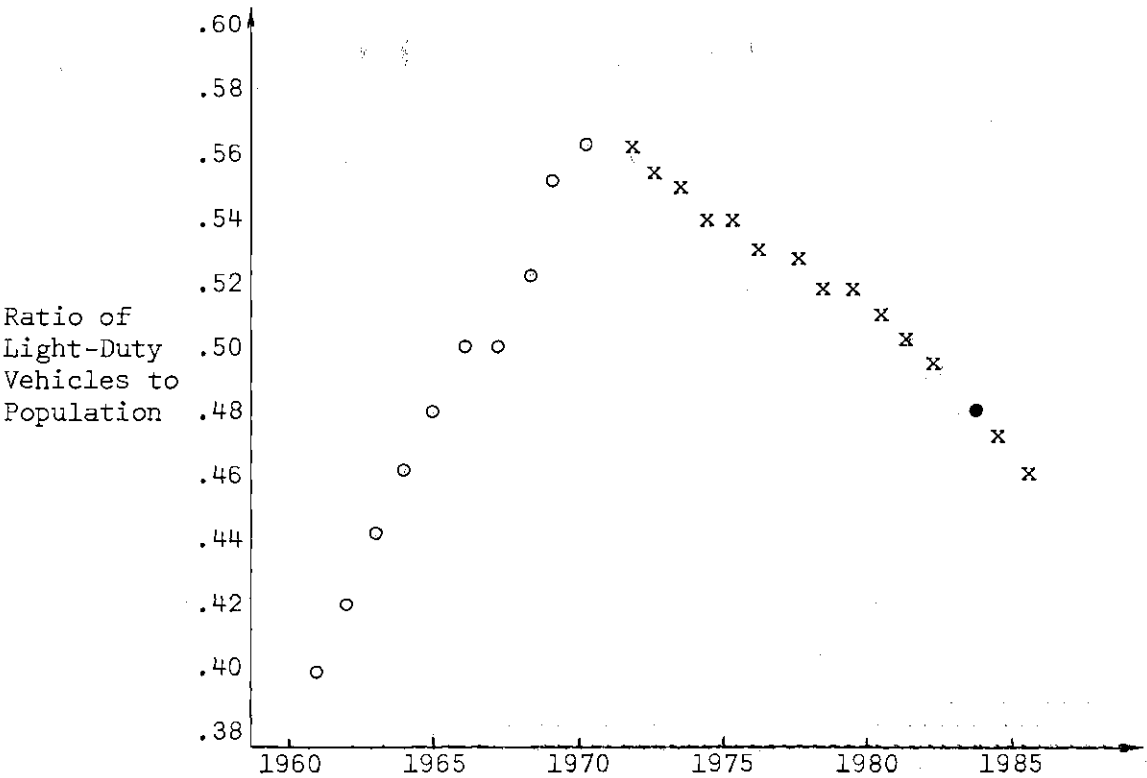
Population estimates from 1961 through 1985 are utilized in PCM and are given in Appendix B.

Ratio of Vehicles to Population. One of the first problems faced in this investigation was estimating the number of light-duty vehicles in 1971-1985. One alternative was to examine historical data and make projections based upon historical growth. This approach was not used. Interviews with the Georgia Department of Revenue, Motor Vehicle Unit, and the Atlanta Region Metropolitan Planning Commission (ARMPC) indicate several pitfalls in using this approach to forecast number of vehicles. Since population estimates for 1971-1985 and a 1983 estimate of vehicle population were received from ARMPC, the decision was made to use the ratio of light-duty vehicles to population as a basis for estimating light-duty vehicles in use. The resulting ratios are presented in Figure 18.

Number of passenger cars (1961-1970) could be obtained directly from registration records. Light-duty gasoline trucks, however, were included in the total truck registration records. Mr. James Lindsey, of the Georgia Motor Vehicle Unit, estimated the light-duty gasoline trucks to be 80 per cent of the total truck population. For this investigation, the total light-duty vehicle population in use is assumed to be passenger cars plus 80 per cent of the total truck population.

The 1983 estimate of vehicles was 841,000 passenger cars. To obtain the number of light-duty trucks, the 1983 passenger car estimate was multiplied by 0.129. The number 0.129 was representative of the 1961-1970 ratio of light-duty trucks to passenger cars.

One may question the use of registration data to estimate actual vehicles in use. Could utilizing registration data lead to double counting? For instance, if vehicle X is registered in Atlanta in 1971 by Mr. A., then sold to Mr. B. living in Atlanta in 1971, would vehicle X be counted as two registrations in Atlanta in 1971? This question was



Symbol	Source of Data
o	Vehicle (registration) data - Motor Vehicle Unit, Georgia Department of Revenue Population data - Atlanta Region Metropolitan Planning Commission
•	Vehicle data - Atlanta Region Metropolitan Planning Commission Population data - Atlanta Region Metropolitan Planning Commission
x	Author's estimate

Figure 18. Projected Ratio of Light-Duty Vehicles to Population in the Five County Metropolitan Atlanta Area

presented by telephone to Mr. Paul Mangold of the Georgia Vehicle Unit. His explanation was that the vehicle in question would be counted in 1971 as one registration and one transfer of title.

Step 2. Vehicle Model Year Populations and Mileage Distributions

After the total number of vehicles had been determined for each year of interest, a breakdown of the total vehicle population into various model year populations was required. The reason for categorizing the total vehicle population into model year populations is because the amount of pollutant generated by a vehicle varies depending upon the model year of the vehicle. Also, since the amount of pollution emitted by a vehicle depends upon the number of miles the automobile is driven, the vehicle mileage per year must be specified.

Probability Age Distribution. The input variable, probability age distribution for vehicles, is used to represent the percentage of passenger cars (out of the total passenger car population) of a given age. On a nationwide basis, the probability age distribution has not significantly changed in the last ten years. Although a vehicle probability age distribution is calculated for the Atlanta Metropolitan Area, the information is considered confidential. Permission was obtained from R. L. Pope Company to use nationwide data for this investigation. The probabilities used in this research are shown in Table 6.

Probability Mileage Distribution. Table 7 gives the annual vehicle mileage driven by a passenger car of a given age. Since the quantity of pollutants generated by a vehicle is a function of the number of miles driven, this is a required parameter for estimating pollutant emissions.

Table 6. Probability Age Distribution
[Source: Reference 3]

Age in Years	Percentage of Total Passenger Cars	Age in Years	Percentage of Total Passenger Cars
0-1	8.4	7- 8	6.3
1-2	11.6	8- 9	5.6
2-3	11.3	9-10	4.5
3-4	10.5	10-11	3.9
4-5	9.2	11-12	3.2
5-6	8.5	12 or More	8.8
6-7	7.7		

Table 7. Passenger Car Use by Age
[Source: Reference 3]

Age in Years	Annual Vehicle Mileage	Age in Years	Annual Vehicle Mileage
0-1	13,200	7- 8	8,100
1-2	12,000	8- 9	7,300
2-3	11,000	9-10	7,000
3-4	9,600	10-11	5,700
4-5	9,400	11-12	4,900
5-6	8,700	12 or More	4,300
6-7	8,600		

The distribution of the mileage by vehicle age groups is necessary to show the year-by-year effect upon total pollutant quantities of older vehicles dropping out of the vehicle population. A spread of 13 years was selected for this investigation.

Step 3. Pollutant Emissions Without Inspection

Calculation of the pollutant emissions without inspection is necessary to estimate an expected maximum amount of pollution to be generated over a given time span. The expected maximum amount of pollution is used in the three equations given previously in this chapter to calculate the measures of inspection system effectiveness.

Before the pollutant emissions without state inspection can be calculated, the model year vehicle population must be divided into two groups: vehicles without exhaust control devices and vehicles with exhaust control devices. If a state inspection system is not implemented, vehicles without control devices emitted pollutants at a constant uncontrolled emission rate. Vehicles with exhaust pollution control devices emit pollutants based upon the amount of deterioration of the exhaust control devices. Deterioration of control devices increases as the cumulative number of miles a vehicle is driven increases. Discussion of the input variables needed to calculate pollutant emissions for controlled and uncontrolled vehicles is now presented.

Uncontrolled Emission Rate for Carbon Monoxide. Pre-1968 light-duty vehicles sold nationwide, except for California, did not have exhaust emission control devices. The input variable, uncontrolled emission rate for carbon monoxide, represents the average grams of carbon monoxide emitted per mile driven by pre-1968 vehicles.

An estimate of the *average* uncontrolled emission rate for carbon monoxide, based upon the 1972 constant volume sampling (CVS) procedure, was received from the Environmental Protection Agency in Atlanta [34].

The uncontrolled emission rate was 110 grams per mile. It should be noted that at this point, no information was available to indicate the variance of the uncontrolled emission rate for pre-1968 vehicles.

To formulate a representative emission rate distribution for pre-1968 vehicles, data from a New Jersey study were utilized [36]. Table 8 was derived from the New Jersey study.

Table 8. Carbon Monoxide Distribution for Pre-1968 Vehicles (Based upon New Jersey Test Procedures) [Source: Reference 36]

Percentage of Total Pre-1968 Vehicles	Exhaust Carbon Monoxide Emissions
0- 10	30 gms/mile
10- 20	40
20- 30	45
30- 40	50
40- 50	60
50- 60	70
60- 70	80
70- 80	110
80- 90	135
90-100	180

The average grams of carbon monoxide per mile based upon the New Jersey data is 80. The average grams per mile based upon the Federal CVS data is 110 grams per mile. Using the ratio of 110 to 80, the New Jersey data were adjusted to be representative of the CVS cycle and is presented in Table 9.

Table 9. Carbon Monoxide Distribution for Pre-1968 Vehicles (Based Upon Adjusting New Jersey Test Procedure Data to Federal CVS Test Procedure)

Percentage of Total Pre-1968 Vehicles	Exhaust Carbon Monoxide Emissions
0- 10	41.1 gms/mile
10- 20	54.8
20- 30	61.7
30- 40	68.5
40- 50	82.2
50- 60	95.9
60- 70	110.0
70- 80	150.7
80- 90	185.0
90-100	246.6

Knowing the emission rate, the number of vehicles and the number of miles driven by pre-1968 vehicles, the total pollutant from pre-1968 vehicles is calculated.

Indicator of the Degree of Federal Control. Light-duty vehicles manufactured after 1967 were required to have exhaust gas emission control systems for carbon monoxide and hydrocarbons. The degree of control achieved for each vehicle model year since 1968 was based upon requirements established by Federal laws. Vehicle manufacturers have devised control systems which initially (at approximately 4000 miles) give lower exhaust emissions than the Federal standards require. The emission levels at 4000 miles for vehicles with control devices are denoted as "base" levels. The input variable, Indicator of the Degree of Federal Control, is used to calculate base level emissions for vehicles with control devices. Carbon monoxide base levels and Federal standards utilized in the PCM computer program are given in Table 10. Base levels and Federal standards for hydrocarbons and nitrogen oxides are given in Appendix C.

Typical and anticipated base levels for 1968-1973 model year light-duty vehicles were received from the Environmental Protection Agency in Atlanta [34]. The ratio of the Federal exhaust standard for 1973 model year light-duty vehicles to the anticipated base level for 1973 model year vehicles was 1.26. Base levels for 1974-1985 model year vehicles were derived in two steps:

1. Review Federal legislative literature to obtain proposed Federal standards [17,18,19,20,21].

2. Apply the 1.26 ratio of Federal emission standards to base levels to calculate the appropriate base levels.

The ratio of the Federal standard for a given year to the base level is assumed to always be 1.26 for carbon monoxide. The assumption of a constant ratio was chosen to simplify an understanding of the model. Any estimate of base level emissions for future vehicles is subjective. Since Federal laws have provisions to allow vehicle manufacturers a one-year postponement in meeting the proposed 1975 carbon monoxide emission standard, 1975 base levels are equal to the 1974 base levels.

<u>Deterioration Equations for Carbon Monoxide</u>. After establishment of base level emissions for vehicles with control devices, the next step involves estimating the increase in pollution from the base level to a

Table 10. Carbon Monoxide Base Level Emissions and Federal Exhaust Standards (Representative of 1972 CVS Test Procedure)

Year	Base Level* Exhaust Emissions	Federal Exhaust Standard**
1968	50.0 gms/mile	63.0 gms/mile
1969	50.0	63.0
1970	35.0	44.0
1971	35.0	44.0
1972	31.0	39.0
1973	31.0	39.0
1974	31.0	39.0
1975	31.0	39.0
1976	3.7	4.7
1977	3.7	4.7
1978	3.7	4.7
1979	3.7	4.7
1980	3.7	4.7
1981	3.7	4.7
1982	3.7	4.7
1983	3.7	4.7
1984	3.7	4.7
1985	3.7	4.7

*The base level is the pollutant emission rate at 4000 miles for vehicles with exhaust control devices. Pollutant emission rates increase from the base levels because of deterioration of control devices.

**In this chapter, refer to discussion of "Indicator of the Degree of Federal Control" and "Federal Exhaust Standards" for necessary assumptions.

higher level because of deterioration of pollution control devices. Deterioration equations allow one to estimate deterioration of control devices. A value of 1.0 for a deterioration equation would imply no deterioration of the exhaust control devices. For vehicles with exhaust control devices, the value of the deterioration equation increases as deterioration of the exhaust control devices occur.

Two deterioration equations per pollutant are used in the PCM computer program. For carbon monoxide, the two equations are:

1. $D = \left(.0048(CCMIS)+1.08\right)\left(1-e^{(-CCMIS/2)}\right)$

2. $D = \left(.0766(CCMIS)+.934\right)\left(1-e^{(-CCMIS/2)}\right)$

where,

D = Deterioration value.

CCMIS = Cumulative vehicle miles in thousands ($CCMIS \geq 4$).

Deterioration equations for hydrocarbons and nitrogen oxides are given in Appendices D and E. Table 11 gives values of deterioration versus cumulative vehicle miles for the two carbon monoxide equations.

The first equation applies to 1968-1975 model year vehicles. The second equation applies to 1976 and later model year vehicles. Two distinct equations are used for the following reasons:

1. The first equation is representative of control devices involving engine modifications. The second equation is representative of add-on control devices such as catalytic converters which will be required to meet future standards.

Table 11. Deterioration Versus Cumulative Vehicle Mileage

Vehicle Age (Years)	Cumulative Mileage (Thousands)	1968-1975 Vehicles	1976 and Later Vehicles
	4.0	1.00	1.00
0- 1	13.2	1.14	1.95
1- 2	25.2	1.20	2.86
2- 3	36.2	1.25	3.71
3- 4	45.8	1.30	4.44
4- 5	55.2	1.34	5.16
5- 6	63.9	1.39	5.83
6- 7	72.5	1.43	6.49
7- 8	80.6	1.47	7.11
8- 9	87.9	1.50	7.67
9-10	94.9	1.54	8.20
10-11	100.6	1.56	8.64
11-12	105.5	1.59	9.02
≥ 12	109.8	1.61	9.34

2. Presently, typical deterioration equations exist only for 1968-1970 vehicles sold nationwide. To simplify the model and because of data constraints, a minimum number of deterioration equations is used. Modifications could be made to incorporate deterioration equations for each vehicle model year as data are analyzed and equations derived.

The equation applicable to 1968-1975 model year vehicles was derived based upon information received from California [25]. The second equation was derived by assuming 1976 and later model year vehicles would deteriorate to the 1973 Federal standard over the lifetime (109,800 miles) of the vehicle.

The PCM computer program utilizes the deterioration values as illustrated in the following example. Suppose the controlled carbon monoxide emission rate for 1973 model year vehicles is 31 grams per mile. On July 1, 1974 a 1973 model year vehicle registers 25,200 miles on its odometer. The deterioration value associated with 25,200 miles is 1.20. On July 1, 1975 the odometer registers 36,200 miles. The deterioration value at 36,200 miles is 1.25. The emission rate between July 1, 1974 and July 1, 1975 would be calculated as follows:

$$\text{Emission Rate} = (31 \text{ grams/mile})\left[(1.20+1.25)/2\right]$$

$$= 38.0 \text{ grams/mile.}$$

To calculate the first year emissions for a *new* vehicle, the PCM program always sets the deterioration value equal 1.0 at 4,000 miles. For example, suppose a new 1973 model year vehicle is driven for one year and its odometer registers 13,200 miles. The deterioration value for 13,200 miles is calculated to be 1.14. The emission rate for the first year would be calculated as follows:

$$\text{Emission Rate} = (31 \text{ grams/mile})\left[(1.00+1.14)/2\right]$$

$$= 33.2 \text{ grams/mile.}$$

Step 4. Pollutant Emissions Assuming Minimum Vehicle Emission Rates

Calculation of the total pollutant emissions assuming minimum vehicle emission rates is necessary to provide a lower limit estimate of the amount of pollution generated over a given time span. The estimated minimum amount of pollution is required to calculate measures of inspection system effectiveness.

With the exception of two details, the procedure is the same as the procedure used to calculate maximum pollutant estimates. That is, the total vehicle population is categorized into model year vehicle populations, which are then classified as either vehicles without control devices (pre-1968 vehicles) or vehicles with control devices (post-1967 vehicles). At this point in the PCM computer program, the minimum pollutant emissions from pre-1968 vehicles and post-1967 vehicles are calculated as discussed below.

Minimum Emissions from Pre-1968 Vehicles. Emission reduction data obtained from a New Jersey study indicates 30 per cent is approximately the maximum carbon monoxide reductions from the total carbon monoxide emissions from pre-1968 vehicles [36]. Therefore, minimum carbon monoxide emissions for pre-1968 vehicles are estimated by calculating 70 per cent of the total emissions assuming no inspection. For hydrocarbons, minimum emissions for pre-1968 vehicles are estimated by calculating 80 per cent of the total hydrocarbon emissions from pre-1968 vehicles [36]. Reductions in pollutants from pre-1968 vehicles is estimated based upon all vehicles obtaining proper engine maintenance to reduce pollution. Other strategies to limit exhaust emissions, such as requiring pollution control devices for pre-1968 vehicles, were not considered because of lack of data.

Minimum Emissions from Post-1967 Vehicles. Minimum emissions from post-1967 vehicles were calculated by assuming vehicles would deteriorate from their base level emissions to the Federal standard. Over the lifetime of the vehicle, emissions never exceed Federal standards.

Federal Exhaust Standards for Carbon Monoxide. Table 10 gives the Federal exhaust standards for carbon monoxide used in this investigation. The table is based upon information as of July 2, 1971. The purpose of this section is to discuss the Federal procedures used in testing a vehicle's compliance with Federal exhaust standards. The dependence of numerical values in Table 10 to the testing and measurement methods is illustrated.

Numerical values in Table 10 should be considered as representative Federal exhaust standards. Several future values have not been finalized. Also, changes in Federal certification testing of vehicles can cause difficulties in calculating numerical values which are correct relative to one another. The following discussion illustrates this last point.

The Federal exhaust carbon monoxide standard for 1968 and 1969 model year light-duty vehicles was expressed as a maximum allowable concentration (vol.). The measurement of the concentration was based upon a seven mode-seven cycle driving cycle [15].

The Federal exhaust standard for 1970 and 1971 model year light-duty vehicles was expressed in terms of grams per mile. The numerical value of the standard was based upon converting carbon monoxide concentrations to the mass standard of grams per mile. To make the conversion, a *theoretical* exhaust gas flow rate was calculated. For example, the equation used to calculate the flow rate for vehicles with automatic transmissions was [16]:

$$\text{Exhaust volume per mile} = (-6.69+0.0277W-0.00000201\ W^2)$$

where,

W = Vehicle inertia weight, in pounds.

On July 15 and November 10, 1970, the Federal government published information on another type of test procedure to calculate grams per mile [17,18]. This procedure, called Constant Volume Sampling (CVS), is applicable to 1972 model year light-duty vehicles. CVS was designed to measure *true* exhaust pollutant *mass* instead of the theoretically calculated pollutant mass. An "exhaust sample bag" collects a proportional part of the exhaust gases. After a specified driving cycle, the exhaust gases collected by the exhaust sample bag are analyzed for the various pollutants. The test procedure was designed to simulate a trip of 7.5 miles, starting from a cold start, in an urban area. A cold start was specified to make the trip representative of a typical morning trip. The numerical values in Table 10 are based upon data representative of the 1972 Constant Volume Sampling test procedure.

Step 5. Pollutant Emissions and Reductions with State Inspection

Pollutant emissions and reductions with state inspection represent the last step required to obtain data values for evaluating inspection system effectiveness. Step 3 described the procedure for estimating an upper limit for the quantity of pollutant emissions. Step 4 presented the procedure for estimating a lower limit for the quantity of pollutant emissions. The data values calculated for Step 5 will lie between the values obtained in Step 3 and Step 5. The discussion for the remainder of Step 5 is as follows:

1. State standards for carbon monoxide.
2. Frequency of inspection.
3. First year pollutant reductions.
4. Pollutant emissions and reductions after the first year.

State Standards for Exhaust Carbon Monoxide. Table 12 gives the state standards for exhaust carbon monoxide used in this investigation. The standards are expressed in terms of the Federal CVS test procedure. Realistically, numerical values chosen for state standards would relate to values based upon diagnostic test procedures which have good correlation with the Federal CVS test procedures.

State standards applicable to post-1967 vehicles were chosen to be 10 per cent above Federal Standards. Ten per cent represents a level which would insure good control over the vehicle population. State standards in this investigation were chosen to be above the Federal standards as opposed to equal the Federal standards, for the following reason. Assembly line testing of new vehicles is not required by law.

Table 12. Carbon Monoxide State Standards

Year	Maximum Allowable Exhaust Emissions*	Year	Maximum Allowable Exhaust Emissions*
Pre-1968	95.9 gms/mile	1977	5.2 gms/mile
1968	69.3	1978	5.2
1969	69.3	1979	5.2
1970	48.4	1980	5.2
1971	48.4	1981	5.2
1972	42.9	1982	5.2
1973	42.9	1983	5.2
1974	42.9	1984	5.2
1975	42.9	1985	5.2
1976	5.2		

*Numerical values are expressed in terms of the 1972 Federal CVS test procedure to allow comparison with the Federal standards.

Therefore, a state could not guarantee with 100 per cent certainty that an individual vehicle was capable of meeting the Federal standard. To reflect this problem of random variation, the margin of 10 per cent above the Federal standard was chosen on the advice of Mr. Robert Collom, Director, Georgia Air Quality Control Branch.

For pre-1968 vehicles, the state standard was established at a point which would give 30 per cent reduction in total carbon monoxide emissions from pre-1968 vehicles. Based upon a New Jersey study, 30 per cent approaches the maximum reductions (assuming engine tune-up only) which can be expected from this group of vehicles [36].

Frequency of Inspection. Several frequencies of inspection were initially considered for this investigation. Considering computer time cost, the decision was made to limit the investigation to annual and biannual inspection.

First Year Pollutant Reductions. The first year of inspection system implementation is important. Several calculations were required to give information concerning the initial behavior of the inspection system. The various types of information are shown in Figure 19.

To calculate the number of vehicles above and below the state standards, vehicle distribution as measured by pollutant emission rate was required. For pre-1968 vehicles, New Jersey data was used. For 1968 and post-1968 vehicles, a normal distribution is assumed. Based upon data given in Table 13, the average carbon monoxide standard deviation for vehicles with control devices was calculated to be .032 times the mean emission value. Realizing that future data could indicate the value .032 was not representative, the PCM was written to require changing only one equation per pollutant to make modifications.

Calculation of pollutant reductions are first made for pre-1968 vehicles. The total reductions are estimated by calculating 30 per cent of the total emissions from pre-1968 vehicles assuming no inspection. A histogram of the vehicle distribution after reductions are achieved is included in the computer program. Overall estimates of reductions are justified because of lack of better data.

PROJECTED FIRST YEAR REDUCTION OF AUTOMOTIVE CO EMISSIONS

WITH INSPECTION (FIVE-COUNTY METRO ATLANTA AREA)

Basic Assumptions

1. *All vehicles will be inspected within the calendar year.*
2. *All vehicles will be inspected on a short-cycle test.*

Calendar Year	Vehicle Model Year	Vehicles Below State Standard	Vehicles Above State Standard	Percentage of Total Above Standard	Total CO Emission Reductions (Tons) From Upper Limit
1975	1975	71,347	0		
	1974	98,526	0		
	1973	95,978	0		
	1972	88,982	201		
	1971	69,742	8,399		
	1970	41,820	30,376		
	1969	28,544	36,857		
	1968	8,233	45,277		
	1967	20,565	13,710		
	1966	15,326	10,218		
	1965	12,371	8,248		
	1964	9,430	6,287		
	1963	24,020	16,014		
				20.7	47,916

Figure 19. Example Printout Giving First Year Behavior of the Inspection System

Table 13. Gross Regression Data, Carbon Monoxide (in Per Cent), 95 Per Cent Confidence Limits, 1968 Model Year California Autos [Source: Reference 25]

Manufacturer	Mileage	Lower Limit	Mean Value	Upper Limit
Chrysler	4,000	0.92	0.98	1.04
	8,000	0.98	1.04	1.10
	16,000	1.04	1.10	1.17
	24,000	1.07	1.14	1.22
	32,000	1.09	1.17	1.26
	40,000	1.10	1.19	1.29
	50,000	1.12	1.22	1.32
Ford	4,000	0.87	0.93	0.99
	8,000	0.95	1.00	1.06
	16,000	1.03	1.09	1.15
	24,000	1.07	1.14	1.22
	32,000	1.10	1.18	1.27
	40,000	1.12	1.21	1.31
	50,000	1.14	1.24	1.35
General Motors	4,000	1.11	1.15	1.20
	8,000	1.23	1.27	1.31
	16,000	1.35	1.40	1.45
	24,000	1.43	1.48	1.54
	32,000	1.48	1.54	1.61
	40,000	1.52	1.59	1.67
	50,000	1.56	1.64	1.73

To calculate emission reductions from post-1967 vehicles, histograms of the vehicle distribution as measured by pollutant emission rate are also established. A histogram is established for *each* vehicle model year. Three steps for each vehicle model year are required to build the histograms. First, the mean emission rate must be calculated. This is calculated by multiplying the base level emission rate times the deterioration factor. Second, the standard deviation of the vehicle population is calculated. The standard deviation is a function of the mean emission rate. Third, given the mean emission rate and the standard deviation, histograms consisting of 13 elements each are constructed. Since it would be meaningless to know the emission rates without knowledge of the number of vehicles associated with the emission rate, a histogram representing the fraction of vehicles of a given model year is also constructed. This histogram is also composed of 13 elements which correspond to the 13 elements of the emission rate histogram.

To estimate reductions, all elements of the emission rate histograms which are above the state standards are reduced to the state standards. For each element of the histograms above the state standards, reductions are calculated by first taking the difference in the emissions before the reduction and emissions at the state standard. Since the number of vehicles associated with each element of the emission rate histogram is known, the total reductions can be calculated.

Pollutant Emissions and Reductions After the First Year. After the first year of the inspection system, vehicles have all been corrected to the state standards. (If a biannual inspection frequency is chosen to be implemented, only one-half the vehicles are assumed to be inspected and, therefore, reductions are equal to one-half the reductions calculated for an annual inspection frequency). The problem to be investigated now is the behavior of the inspection system after the first year of inspection system implementation. Figure 20 gives an example calculation made in computing behavior of an annual inspection system.

PROJECTED AUTOMOTIVE CO EMISSIONS WITH INSPECTION

Basic Assumptions

1. *All vehicles will be inspected on a short-cycle test.*
2. *All vehicles will be inspected each year.*

Calendar Year	Total CO Emissions (Tons)	Reduction from Total CO Emissions (Tons)
1976	367,943	4,294
1977	329,113	7,935
1978	281,666	10,830
1979	246,161	13,139
1980	208,225	14,796
1981	178,937	16,234
1982	146,783	17,397
1983	127,798	18,280
1984	110,642	18,795
1985	98,903	19,148

Figure 20. Example Printout Giving Behavior of the Inspection System After the First Year of Implementation

A constant rate of increase in the pollutant emission rate for each vehicle model year is calculated. The constant rate of increase is utilized as illustrated below:

$$X_1 = X_0 + S(M_n)$$

where,

X_1 = The end of the year emission rate for a particular element in the emission rate histogram (grams/mile).

X_0 = The beginning of the year emission rate for a particular element in the emission rate histogram (grams/mile).

S = Constant rate of increase in pollutant emission rate (grams/mile/mile).

M_n = Number of miles driven in a given year by a vehicle of age n.

For pre-1968 vehicles, the constant rate of increase for carbon monoxide was calculated based upon an 11 gram per mile increase over 10,000 miles. For hydrocarbons, the constant rate of increase from pre-1968 vehicles was assumed to be a 1.3 gram per mile increase in 10,000 miles. Since pre-1968 vehicles do not have control devices, these values are assumed to be representative of vehicles which would have defective spark plugs, carburetors, or other engine malfunctions.

For post-1967 vehicles, the constant rate of increase was calculated based upon the increase in the pollutant emission rate between 50,000 miles and 60,000 miles for each vehicle model year. The number 50,000 miles was chosen because California data indicate emissions can begin to exceed Federal standards at approximately this mileage level. An inspection system would be designed to assure an emissions rate that approximates the Federal standards.

After the constant rates of pollutant increases have been calculated, the following cycle of events occurs for *each* year of investigation:

1. Histograms are established for each new vehicle model year introduced into the vehicle population.

2. Constant rates of pollutant increase are added to each pollutant emission rate histogram (except the histogram established in Step 1).

3. Total pollutant emissions are calculated.

4. All elements of each emission rate histogram are compared to the state standards.

5. Histogram elements above the state standards are reduced to the state standard. Pollutant reductions are simultaneously calculated in this step.

6. Total pollutant emissions and total pollutant reductions are printed.

CHAPTER V

MEASURES OF COST AND PERFORMANCE

Introduction

To determine the feasibility of various methods of inspecting automobiles, two important parameters were considered. First, the cost of inspection and second the vehicle waiting time associated with the inspection. In this investigation, three measures of the cost of an inspection system are estimated; they are investment cost, total equivalent annual cost, and breakeven cost per vehicle.

This chapter describes the methods employed to measure the cost and related vehicle waiting times for various inspection system configurations. The first section of the chapter gives the required assumptions. Next, the method of evaluation is explained followed by the details of the evaluation methodology.

Inspection System Configuration Assumptions

Permanent Facilities

Several alternatives were initially considered for inspecting vehicles. Briefly stated, they are:

1. Utilize existing safety inspection service stations.
2. Utilize shopping center parking lots.
3. Utilize a downtown parking lot plus shopping center parking lots.
4. Utilize permanent facilities owned and operated by state personnel.

Since a short cycle type of test, requiring a chassis dynamometer, was considered essential for measuring exhaust emissions, utilization of the existing safety inspection service stations is questionable. Utilizing shopping center parking lots would require mobile facilities. Mobile facilities are also questionable since delicate testing equipment will be required to inspect a large volume of vehicles.

The assumption is made that permanent facilities, state owned and operated, will be used to inspect vehicles. This would allow vehicle inspection to be performed utilizing a short cycle test. Also, it is reasonable to believe permanent facilities are more capable (than mobile facilities) of inspecting the total vehicle population in the Atlanta Metropolitan Area. Figure 21 illustrates the basic floor plan for a one and a five lane facility.

Inspection System Characteristics

Six characteristics of the inspection system affect the cost of inspection. They are:

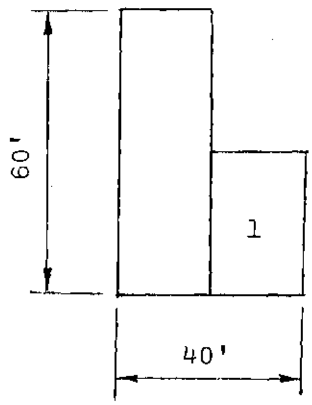
1. Vehicles are inspected on a short cycle diagnostic test.

2. Inspection facilities operate 250 days per year, 8 hours per day.

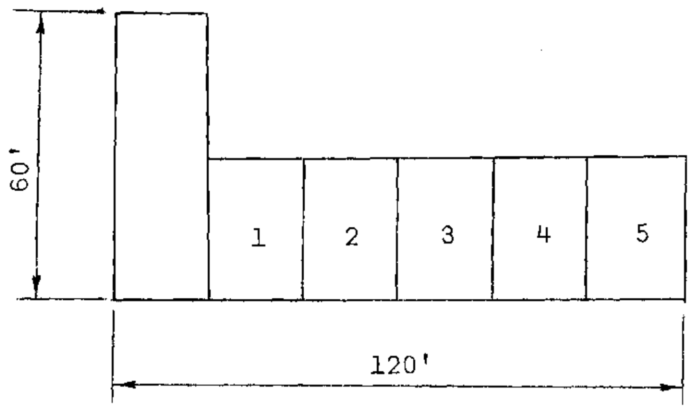
3. Vehicles are assumed to arrive at the inspection facility according to a Poisson probability density function (random but at a certain average arrival rate).

4. Vehicles are assumed to be inspected completely at a constant service time of 15 minutes.

5. Inspection may be annual or biannual.



One Lane Inspection Facility



Five Lane Inspection Facility

Figure 21. One and Five Lane Inspection Facilities (Basic Floor Plans)

6. Approximately 20 per cent of the vehicles are assumed to fail the inspection test and therefore, will require a recheck.

Types of Inspection System Configurations Evaluated

Inspection system configurations evaluated in this investigation are:

1. All one lane inspection facilities,
2. All two lane inspection facilities,
3. All three lane inspection facilities,
4. All four lane inspection facilities,
5. All five lane inspection facilities.

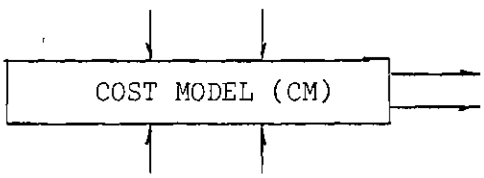
Method of Evaluation

Since the cost associated with several inspection system configurations is of interest in this study , a computer model was developed to generate inspection system configurations and compute their costs. Figure 22 gives the inputs and outputs required for the cost model, denoted CM. Design parameters representing population, ratio of vehicles to population, etc., are inputs to the cost and waiting time calculations. The state air pollution control agency has little control over the input design parameters since they are affected by exogenous forces. Input design variable, such as annual or biannual inspection, are utilized to evaluate policy decisions.

The CM computer program is written in Fortran IV. The CM was processed on the Georgia Institute of Technology's Univac 1108. Approximately 40 seconds per evaluation are required. Waiting time calculations account for the bulk of the computer time.

Input Design Parameters

Facility Space Requirements
Population
Ratio of Vehicles to Population
Interest Rate
Cost of Land
Cost of Building Construction
Cost of Paving
Cost of Test Equipment
Cost of Office Equipment
Cost of Salaries



Outputs

Number of Facilities
Utilization
Investment Cost
Annual Cost
Cost per vehicle
Total Expected Waiting Time

Input Design Variables

Annual or Biannual Inspection
Design Capacity

Figure 22. Inputs and Outputs of the Cost Model

Details of Evaluation Methodology

The remainder of this chapter discusses the methodology employed in evaluating the cost of inspection for the Atlanta Metropolitan Area between 1975 and 1985. The expected waiting time calculations are also presented.

The CM was utilized to make the calculations of costs and waiting time. A flow diagram of the CM calculations is given in Appendix F. Figure 22 gives the inputs and outputs of the CM.

Estimating the Minimum Number of Facilities Required

When designing for the minimum number of facilities required to inspect vehicles in the Atlanta Metropolitan Area, a safety factor should be considered to allow for equipment breakdowns, test equipment calibrations, vehicle rechecks above the assumed 20 per cent and possible underestimates of vehicle population. For these reasons, the minimum number of required facilities is calculated based upon the inspection system reaching a given design capacity by 1985. The design capacity is an input variable to the CM and was chosen to be 80 per cent for this investigation. Designing for 80 per cent capacity by 1985 allows the inspection system to begin in 1975 with a capacity of approximately 72 per cent. Also, designing for 72-80 per cent capacity allows flexibility to add inspection of diesels or other types of mobile combustion sources to the state inspection. Other studies have used a similar approach to reflect a realistic inspection system [7]. The number of vehicles to be inspected in 1985 is estimated to be 959,560 (if annual inspection is instituted) or 479,780 (if biannual inspection is instituted).

The basic equation used to calculate the minimum number of facilities is:

$$F = \frac{N\left(\frac{1+R}{C}\right)}{(250)(8)(4)S}$$

where,

F = Minimum number of facilities.

N = Number of vehicles to be inspected in 1985.

R = Fraction of N failing the inspection test.

C = Design capacity (expressed as a fraction).

250 = Days per year an inspection facility is open to the public.

8 = Hours per day an inspection facility is open to the public.

4 = Maximum service rate (vehicles/lane/hour).

S = Number of lanes (1-5) per facility.

Investment Cost Calculations

Facilities. Table 14 gives area requirements and cost factors used in this investigation to estimate investments in facilities. Area requirements are based on a study by Clayton Manufacturing Company for the state of Wisconsin [7].

Table 14. Space Requirements and Investment Cost Factors per Facility

Facility	Space Requirements (Square Feet)		
	Land[a]	Building[b]	Paving[c]
One Lane	33,750	1,800	31,950
Two Lane	38,750	2,400	36,350
Three Lane	43,750	3,000	40,750
Four Lane	48,750	3,600	45,150
Five Lane	53,750	4,200	49,550

NOTE: a. Land at \$.22/sq.ft.
b. Building construction at \$10/sq.ft.
c. Paving at \$.33/sq.ft.

The cost of land for this investigation is based upon $10,000 per acre. This number is an average for Metropolitan Atlanta (August, 1971) and was obtained from the Department of Real Estate and Urban Affairs, Georgia State University, Atlanta, Georgia.

The cost of construction varies depending upon factors such as type of construction material used and size of the facilities. Several construction companies in the Metropolitan Atlanta area estimate the cost of building construction ranges from $8 to $12 per square foot.

The average cost of asphalt paving in the Atlanta Metropolitan area is $ .33 per square foot. The number was provided by the Georgia Asphalt Paving Association and a large construction company in Atlanta. Site preparation is estimated to be 5 per cent of the building cost [7].

Equipment. The cost of office equipment is estimated to be $2500 per facility [7]. This includes expenditures for items such as typewriters, chairs, tables, and desk for the inspection facility.

The cost of required test equipment is based upon information received from Clayton Manufacturing Company [8]. Dr. Samuel Shelton, School of Mechanical Engineering, Georgia Institute of Technology, assisted in determining equipment needs for a diagnostic type of inspection test. The investment in test equipment per inspection lane is as follows:

1.	Chassis dynamometer (for steady state testing)	$1,853
2.	Suppressed zero MPH instrument for ceiling mount	225
3.	Readout panels (MPH/CO/HC/NO)	779

4.	Exhaust gas analyzers (CO/HC/NO)	3,000
5.	Installation	1,025
		$6,882

Total Equivalent Annual Cost

Fixed Annual Cost. To determine equivalent annual cost, an 8 per cent interest rate is used. Since the public will be financing the inspection system through taxation and inspection fees, 8 per cent is chosen to be representative of the value of money to a citizen in the Atlanta Metropolitan area.

Capital recovery and interest are calculated using appropriate formulas in engineering economy [42]. Those items requiring substantial initial investment have the following estimated lives and salvage values:

Item	Estimated Life (Years)	Salvage Value (% of First Cost)
Land	30	100
Building	30	0
Paving	30	0
Site Preparation	30	0
Office Equipment	10	15
Test Equipment	10	10

Labor costs are presented in Table 15. Except for the director's salary, salaries are based upon an area wage survey for Metropolitan Atlanta [2]. The director's salary is based upon a study by Clayton Manufacturing Company for Wisconsin [7].

Costs of lights, heating and air conditioning were estimated by calculating power requirements and then applying local commercial rates. The following equations were developed for determining these costs:

Cost of lights/facility = 60 + 45s

Cost of gas/facility = 78.80 + 37.25s

Cost of air conditioning/facility = 35.28s

where,

s = Number of lanes per facility.

Table 15. Personnel and Salary Requirements for Inspection Facilities

Personnel	Salary	Fixed or Variable
1 Director per facility	$13,198/year	Fixed
1 Cashier per facility	2.59/hour	Fixed
1 Janitor per facility	2.16/hour	Fixed
1 Trainee per facility	2.36/hour	Fixed
1 Auto Mechanic per lane	3.93/hour	Variable
1 Technician per lane	2.36/hour	Variable

Costs of maintenance of equipment are estimated to be $150 for a chassis dynamometer [8] and $350 for a set of exhaust gas analyzers (CO,HC,NO). The $350 is an assumed cost factor.

Variable Annual Cost. There are certain costs that vary with the level of activity (number of cars inspected). These costs are called variable cost. The variable cost items considered in this investigation are inspection stickers, inspection supplies, power for the chassis dynamometer and labor directly associated with testing the vehicles.

Inspection stickers are estimated to be \$.25 per vehicle. This is based upon the current price of the safety inspection sticker used in Georgia [22]. Inspection supplies are considered to be \$.045 per vehicle. This is the cost of the triplicate forms used in the Georgia safety inspection [22]. The cost of power associated with a chassis dynamometer is estimated to be \$.015 per vehicle. This power is for a 30-horsepower hydraulic absorber required with the chassis dynamometer.

Labor costs are given in Table 15. Salaries are based upon an area wage survey for the Atlanta Metropolitan Area [2].

<u>Breakeven Cost per Vehicle</u>

The breakeven cost per vehicle is the cost Georgia would be required to charge each motorist to breakeven on the operation of an inspection system. The breakeven cost is calculated simply by dividing the total equivalent annual cost by the number of vehicles inspected. Vehicles which fail the inspection test are assumed not to be charged for the recheck.

<u>Expected Waiting Time Calculations</u>

Expected waiting time is a criterion used in evaluating the actual operating performance of various inspection system configurations. To calculate expected waiting time per vehicle (customer) the following assumptions are made:

1. Customers arrive at the inspection facilities as described by a Poisson probability density function [24].

2. Customers are serviced at a constant rate equal to 15 minutes per vehicle.

3. Customers arriving at the inspection facilities do not leave until their vehicle is inspected.

4. Infinite customer population is assumed.

The arrival rate is calculated based upon the total number of vehicles and the total number of hours the facilities are open to the public. The assumption of an infinite customer population is justified because of the large number of vehicles in the Atlanta Metropolitan Area and the fact that a customer may be inspected at any facility in the Atlanta Metropolitan Area.

The equation for expected waiting time (in queue) is calculated as follows [12,38]:

$$w = \sum_{i=1}^{\infty} e^{-sui} \left[\sum_{\mu=is}^{\infty} \frac{(sui)^{\mu}}{\mu!} - \frac{1}{u} \sum_{\mu=is+1}^{\infty} \frac{(sui)^{\mu}}{\mu!} \right]$$

where,

s = Number of lanes per facility.

u = Average utilization per lane (0.00-1.00).

The value for w as calculated above is expressed in multiples of the servicing time. The total waiting time (time in the queue plus the time being serviced) is calculated as follows:

$$\text{Total waiting time} = wh + h$$

where,

h = Mean servicing time (hours).

Calculating Costs for Additional Configurations

The calculation of the minimum number of inspection facilities required produced five inspection system configurations. By incrementing the minimum number of inspection facilities required by six, additional inspection system configurations are generated. The costs of the new inspection system configurations are calculated using the same methodology as presented previously in this chapter.

CHAPTER VI

INVESTIGATION RESULTS

Introduction

The purpose of this chapter is to present and discuss cost-effectiveness results of this investigation. To identify variables which should be given careful consideration when designing and evaluating an automotive inspection system, sensitivity analysis is also performed. Results are for the Atlanta Metropolitan Area. Measures of effectiveness and cost are based upon the methodologies described in Chapter IV and Chapter V, respectively.

Cost Effectiveness Results

Effectiveness of State Inspection

Three measures of effectiveness are required to evaluate a proposed inspection system. They are:

1. Percentage of uncontrolled level emitted with inspection.
2. Total estimated reductions in tons per year.
3. Percentage of potential reductions achieved by inspection.

The remainder of this section will discuss the three measures of effectiveness by giving the total pollutant emissions and the total pollutant reductions achieved with state inspection.

Total Pollutant Emissions. Table 16 gives the total pollutant emissions expected each year with no state inspection of automobiles.

Table 16. Estimated Minimum and Maximum Pollutant Emissions (1975-1985)

	Minimum Emissions with State Inspection			Maximum Emissions without State Inspection		
Year	Carbon Monoxide (Tons)	Hydro-carbons (Tons)	Nitrogen Oxides (Tons)	Carbon Monoxide (Tons)	Hydro-carbons (Tons)	Nitrogen Oxides (Tons)
1974	488,140	52,103	42,376	488,140	52,103	42,376
1975	403,255	41,907	39,506	462,356	48,257	40,445
1976	357,055	35,939	34,532	406,950	41,609	36,111
1977	307,943	30,262	29,765	355,764	35,708	32,057
1978	256,550	24,823	24,896	306,458	30,341	28,023
1979	218,016	20,897	21,248	273,495	26,835	25,378
1980	177,706	16,092	18,019	234,832	22,217	23,064
1981	148,571	13,504	15,154	212,201	20,334	21,095
1982	117,595	10,598	12,286	187,564	18,061	19,078
1983	99,301	9,038	10,584	175,915	17,252	18,088
1984	83,148	9,668	8,948	164,962	16,524	17,051
1985	72,122	6,725	7,625	158,867	16,170	16,599

The decrease in total emissions is attributed to the decrease in base level emissions for new vehicles plus the attrition of older vehicles possessing no pollution control devices. Table 16 also gives the minimum level of emissions expected each year with the introduction of state inspection of automobiles. The minimum emission calculations assume vehicles without control devices will remain in tune and vehicles with control devices will not exceed Federal pollution standards.

To see the effects of inspection frequency, Tables 17 and 18 give total pollutant emissions for annual and biannual inspection. Tables 17 and 18 are important because they indicate that for carbon monoxide and hydrocarbons the level of pollutant emissions and the percentage of maximum emissions decrease from 1975 through 1985.

Table 17. Estimated Pollutant Emissions with Annual State Inspection (1975-1985)

	CARBON MONOXIDE			HYDROCARBONS			NITROGEN OXIDES		
	Level		Percent of Potential Reductions Achieved	Level		Percent of Potential Reductions Achieved	Level		Percent of Potential Reductions Achieved
Year	(Tons)	(Percent of Maximum Level)		(Tons)	(Percent of Maximum (Level)		(Tons)	(Percent of Maximum Level)	
1974	488,140	100	-	52,103	100	-	42,376	100	-
1975	414,440	90	82	43,940	91	68	40,224	99	24
1976	365,796	90	82	38,829	93	54	36,019	100	6
1977	325,145	91	64	32,829	92	53	31,806	99	10
1978	276,251	90	61	27,304	90	55	27,416	98	19
1979	239,591	88	61	23,279	87	60	23,924	94	35
1980	200,827	86	59	18,397	83	62	20,723	90	46
1981	170,820	80	65	15,661	77	68	17,776	84	56
1982	138,085	74	71	12,565	70	74	14,700	77	64
1983	118,658	67	75	10,917	63	77	13,807	76	57
1984	101,244	61	78	9,446	57	80	12,155	71	60
1985	89,329	56	80	8,455	52	82	9,284	56	82

Table 18. Estimated Pollutant Emissions with Biannual State Inspection (1975-1985)

	CARBON MONOXIDE			HYDROCARBONS			NITROGEN OXIDES		
	Level		Percent of Potential Reductions Achieved	Level		Percent of Potential Reductions Achieved	Level		Percent of Potential Reductions Achieved
Year	(Tons)	(Percent of Maximum Level)		(Tons)	(Percent of Maximum Level)		(Tons)	(Percent of Maximum Level)	
1974	488,140	100	-	52,103	100	-	42,376	100	-
1975	438,398	95	40	46,098	96	34	40,335	100^-	12
1976	367,943	90	78	38,847	93	49	36,111	100^-	0^+
1977	326,834	92	60	33,056	93	49	31,909	100^-	6
1978	281,666	92	50	27,902	92	44	27,871	99	5
1979	244,206	89	53	23,773	89	52	24,325	96	25
1980	208,225	89	46	19,169	86	50	21,387	93	33
1981	177,100	83	55	16,321	80	59	17,346	82	63
1982	146,783	78	58	13,485	75	61	15,478	81	53
1983	126,045	72	65	11,702	68	68	12,469	69	75
1984	110,642	67	66	10,452	63	69	12,997	76	50
1985	97,262	61	71	9,307	58	73	10,004	60	73

This implies that state inspection is maintaining control over the vehicle population and is becoming more effective as time increases. An important assumption about deterioration of post-1975 model year vehicles is that exhaust pollutant control devices will deteriorate, over the lifetime of the vehicle, to the 1973 Federal exhaust pollutant standards.

For nitrogen oxides the level of pollutant emissions is rapidly decreasing, while the percentage of the maximum emissions does not decrease substantially until approximately 1979. The reason the inspection system does not substantially lower the level of nitrogen oxide emissions from 1975-1978 is because control devices for nitrogen oxides will not have deteriorated to a level where state inspection can be effective. Control devices for nitrogen oxides are not anticipated nationwide until 1973. Also, no state nitrogen oxide standards are assumed for pre-1973 model year vehicles. Unfortunately, corrective measures (such as engine tune-ups) which reduce exhaust emissions of hydrocarbons and carbon monoxide for pre-1973 vehicles tend to increase the levels of nitrogen oxides formed.

Total Pollutant Reductions. Table 19 presents total pollutant reductions with annual or biannual inspection. Results given in Table 19 provide one method for evaluating the cost effectiveness of state inspection.

Results indicate that, in general, reductions decrease from approximately 1975 to 1978, then increase from 1978 to 1985. The decrease in reductions is because in the first year of inspection system implementation, substantial reductions will be achieved which could not be equalled in 1976 and 1977. Also, the total emissions without state inspection were decreasing rapidly because of federal action causing reductions in base level emissions for 1973-1976 model year vehicles.

Table 19. Estimated Pollutant Reductions with Annual or Biannual Inspection (1975-1985)

	Total Reductions with Annual Inspection			Total Reductions with Biannual Inspections		
Year	Carbon Monoxide (Tons)	Hydro-carbons (Tons)	Nitrogen Oxides (Tons)	Carbon Monoxide (Tons)	Hydro-carbons (Tons)	Nitrogen Oxides (Tons)
1975	47,916	4,317	221	23,958	2,159	110
1976	41,154	3,044	92	39,007	2,762	0+
1977	30,619	2,874	215	28,930	2,652	148
1978	30,207	3,037	607	24,792	2,439	152
1979	33,504	3,556	1,454	29,289	3,062	1,053
1980	33,205	3,820	2,341	25,807	3,048	1,677
1981	41,381	4,673	3,319	35,101	4,013	3,749
1982	49,479	5,496	4,378	40,781	4,576	3,600
1983	57,257	6,335	4,281	49,870	5,550	5,619
1984	63,718	7,078	4,896	54,320	6,072	4,054
1985	69,538	7,715	7,315	61,605	6,863	6,595

The increases in reductions achieved by the inspection system from 1978-1985 are explained as follows. The rate of deterioration assumed for pollutant control devices on 1976-1985 model year vehicles is greater than the rate of deterioration assumed for pre-1976 model year vehicles. With a higher rate of deterioration plus an increasing vehicle population, the effectiveness of state inspection, in terms of pollutant reductions, begins to increase in 1978.

Biannual inspection compares favorably with annual inspection. Table 20 gives total emission reductions with annual and biannual inspection. Also, Table 20 indicates the maximum possible reductions achievable with state inspection. The maximum possible reductions achievable are calculated by subtracting the minimum emissions with state inspection (FY 1975-1985) in Table 16 from the maximum emissions without state inspection (FY 1975-1985) also given in Table 16.

Table 20. Comparison of Total Estimated Pollutant Reductions Achieved with Annual vs. Biannual Automotive Inspection (1975-1985)

Pollutant	Total Emission Reductions Achieved		Maximum Possible Reductions Achievable (Tons)
	Biannual Inspection (Tons)	Annual Inspection (Tons)	
CO	413,460	498,378	697,302
HC	43,196	51,950	75,855
OX	26,729	29,155	54,426

Cost of State Inspection

The people with the responsibility for funding state inspection of automotive pollution control devices are interested in the cost impact of such a system on the state and the public. Those people within state government who must find the money to finance the project are interested in the initial investment required and the operating expenses. Because the public will be required to pay for the inspection system, it is also important to know the inspection cost per vehicle.

Cost data for 60 inspection system configurations, which will inspect all vehicles in the Atlanta Metropolitan Area, was generated by the cost model described in Chapter V. Thirty of the 60 configurations are for annual inspections and the remaining configurations are for biannual inspections. Tables 21, 22, 23, 24, 25 and 26 summarize the results for each of the 60 inspection system configurations. A discussion of the cost results in Tables 21 through 26 is now given.

Investment Cost. Investment cost results illustrate two important factors which should be considered when designing an inspection system. For inspection system configurations with comparable utilization, (1) the investment cost of test equipment is approximately the same and (2) the investment cost for the other expenditures varies considerably. Therefore, investment cost factors such as type of building construction (e.g. brick versus concrete block) should be given careful consideration in the design of the inspection facilities. In this study an average cost per square foot was utilized. Also, the incremental investment cost in designing for all one lane facilities versus all two lane facilities indicates the importance of utilizing one office area to handle customers from either a one lane or a multiple lane facility. Since inspection facilities were assumed to operate only eight hours per day, the number of facilities required is greater than a double shift (i.e., two eight-hour shifts) would require.

Since biannual inspection assumes inspection of one-half the vehicle population each year, the cost of investments for biannual inspection is approximately one-half that of annual inspection.

Table 21. Investment Costs ($\$ \times 10^6$) for Annual Inspection

Configuration	Number of Facilities	Lanes per Facility	Utilization 1975	Utilization 1980	Utilization 1985	Investment Test Equipment	Investment Other
A 1	179	1	71	78	80	$1.23	$7.05
A 2	185	1	69	75	78	1.27	7.28
A 3	191	1	67	73	75	1.31	7.52
A 4	197	1	65	71	73	1.36	7.76
A 5	203	1	63	68	71	1.40	8.00
A 6	209	1	61	67	69	1.44	8.23
A 7	89	2	72	78	81	1.22	4.29
A 8	95	2	67	73	76	1.31	4.58
A 9	101	2	63	69	71	1.39	4.87
A10	107	2	60	65	67	1.47	5.16
A11	113	2	56	62	64	1.56	5.45
A12	119	2	54	58	60	1.64	5.74
A13	59	3	72	78	81	1.22	3.37
A14	65	3	65	71	73	1.34	3.71
A15	71	3	60	65	67	1.47	4.05
A16	77	3	55	60	62	1.59	4.39
A17	83	3	51	56	58	1.71	4.74
A18	89	3	48	52	54	1.84	5.08
A19	44	4	72	79	82	1.21	2.90
A20	50	4	64	70	72	1.38	3.30
A21	56	4	57	62	64	1.54	3.69
A22	62	4	51	56	58	1.71	4.09
A23	68	4	47	51	53	1.87	4.48
A24	74	4	43	47	49	2.04	4.88
A25	35	5	73	79	82	1.20	2.62
A26	41	5	62	68	70	1.41	3.07
A27	47	5	54	59	61	1.62	3.51
A28	53	5	58	52	54	1.82	3.96
A29	59	5	43	47	49	2.03	4.41
A30	65	5	39	42	44	2.24	4.86

Table 22. Investment Costs ($ × 10^6) for Biannual Inspection

Configuration	Number of Facilities	Lanes per Facility	Utilization 1975	Utilization 1980	Utilization 1985	Investment: Test Equipment	Investment: Other
B 1	89	1	72	78	81	$ .61	$3.50
B 2	95	1	67	73	76	.65	3.74
B 3	101	1	63	69	71	.70	3.98
B 4	107	1	60	65	67	.74	4.21
B 5	113	1	56	62	64	.78	4.45
B 6	119	1	54	58	60	.82	4.68
B 7	44	2	72	79	82	.61	2.12
B 8	50	2	63	70	72	.69	2.41
B 9	56	2	57	62	64	.77	2.70
B10	62	2	51	56	58	.83	2.99
B11	68	2	47	51	53	.94	3.28
B12	74	2	43	47	49	1.02	3.57
B13	29	3	73	80	83	.60	1.66
B14	35	3	61	66	69	.72	2.00
B15	41	3	52	57	58	.85	2.34
B16	47	3	45	49	51	.97	2.68
B17	53	3	40	44	45	1.09	3.02
B18	59	3	36	39	41	1.22	3.37
B19	22	4	72	79	82	.61	1.45
B20	28	4	57	62	64	.77	1.85
B21	34	4	46	51	53	.94	2.24
B22	40	4	40	43	45	1.10	2.64
B23	46	4	35	38	38	1.27	3.03
B24	52	4	31	33	35	1.43	3.06
B25	17	5	75	82	85	.58	1.27
B26	23	5	55	60	63	.79	1.72
B27	29	5	43	48	50	1.00	2.17
B28	35	5	36	40	41	1.20	2.62
B29	41	5	31	34	35	1.41	3.07
B30	47	5	27	30	31	1.62	3.51

Table 23. Total Equivalent Annual Cost ($\$ \times 10^6$) for Annual Inspection

Configuration	Capital Recovery with Return	Labor Fixed	Labor Variable	Other Expenses Fixed	Other Expenses Variable	Total Equivalent Annual Cost
A 1	$.81	$4.91	$2.25	$.14	$.29	$8.40
A 2	.84	5.07	2.33	.14	.29	8.67
A 3	.86	5.24	2.40	.14	.29	8.93
A 4	.89	5.40	2.48	.15	.29	9.21
A 5	.92	5.57	2.55	.15	.29	9.48
A 6	.94	5.73	2.63	.16	.29	9.75
A 7	.56	2.44	2.24	.12	.29	5.65
A 8	.59	2.60	2.39	.13	.29	6.00
A 9	.63	2.77	2.54	.13	.29	6.36
A10	.67	2.93	2.69	.14	.29	6.72
A11	.71	3.10	2.84	.15	.29	7.09
A12	.74	3.26	2.99	.16	.29	7.44
A13	.47	1.62	2.23	.11	.29	4.72
A14	.52	1.78	2.45	.12	.29	5.16
A15	.57	1.95	2.68	.14	.29	5.63
A16	.61	2.11	2.91	.15	.29	6.07
A17	.66	2.28	3.13	.16	.29	6.52
A18	.71	2.44	3.36	.17	.29	6.97
A19	.43	1.21	2.21	.11	.29	4.25
A20	.49	1.37	2.52	.13	.29	4.80
A21	.54	1.54	2.82	.14	.29	5.33
A22	.60	1.70	3.12	.16	.29	5.87
A23	.66	1.86	3.42	.17	.29	6.40
A24	.72	2.03	3.72	.19	.29	6.95
A25	.40	.96	2.20	.11	.29	3.96
A26	.47	1.12	2.58	.13	.29	4.59
A27	.54	1.29	2.96	.14	.29	5.22
A28	.61	1.45	3.33	.16	.29	5.84
A29	.68	1.62	3.71	.18	.29	6.48
A30	.74	1.78	4.09	.20	.29	7.10

Table 24. Total Equivalent Annual Cost ($\$ \times 10^6$) for Biannual Inspection

Configuration	Capital Recovery with Return	Labor Fixed	Labor Variable	Other Expenses Fixed	Other Expenses Variable	Total Equivalent Annual Cost
B 1	$.40	$2.44	$1.12	$.07	$.14	$4.17
B 2	.43	2.60	1.20	.07	.14	4.44
B 3	.46	2.77	1.27	.08	.14	4.72
B 4	.48	2.93	1.35	.08	.14	4.98
B 5	.51	3.10	1.42	.09	.14	5.26
B 6	.54	3.26	1.50	.09	.14	5.53
B 7	.28	1.21	1.11	.06	.14	2.80
B 8	.31	1.37	1.26	.07	.14	3.15
B 9	.35	1.54	1.41	.07	.14	3.51
B10	.39	1.70	1.56	.08	.14	3.87
B11	.43	1.86	1.71	.09	.14	4.23
B12	.46	2.03	1.86	.10	.14	4.59
B13	.23	.80	1.09	.06	.14	2.32
B14	.28	.96	1.32	.07	.14	2.77
B15	.33	1.12	1.55	.08	.14	3.22
B16	.38	1.29	1.77	.09	.14	3.67
B17	.42	1.45	2.00	.10	.14	4.11
B18	.47	1.62	2.23	.11	.14	4.57
B19	.21	.60	1.11	.05	.14	2.11
B20	.27	.77	1.41	.07	.14	2.66
B21	.33	.93	1.71	.09	.14	3.20
B22	.39	1.10	2.01	.10	.14	3.74
B23	.45	1.26	2.31	.12	.14	4.28
B24	.51	1.43	2.62	.13	.14	4.83
B25	.19	.47	1.07	.05	.14	1.92
B26	.26	.63	1.45	.07	.14	2.55
B27	.33	.80	1.82	.09	.14	3.18
B28	.40	.96	2.20	.10	.14	3.80
B29	.47	1.12	2.58	.13	.14	4.44
B30	.53	1.29	2.96	.14	.14	5.06

Table 25. Cost per Vehicle per Year Versus Total Waiting Time for Annual Inspection

Configuration	Cost per Vehicle per Year 1975	1980	1985	Total Waiting Time (Hrs.) 1975	1980	1985
A 1	$9.90	$9.07	$8.76	.56	.68	.76
A 2	10.22	9.36	9.05	.52	.62	.69
A 3	10.54	9.66	9.33	.50	.58	.63
A 4	10.86	9.95	9.61	.48	.55	.59
A 5	11.18	10.24	9.90	.46	.52	.55
A 6	11.50	10.54	10.18	.45	.50	.53
A 7	6.66	6.11	5.90	.39	.45	.49
A 8	7.09	6.49	6.27	.35	.40	.42
A 9	7.51	6.88	6.65	.34	.37	.38
A10	7.94	7.27	7.03	.32	.34	.36
A11	8.36	7.66	7.40	.31	.33	.34
A12	8.79	8.05	7.78	.30	.32	.33
A13	5.57	5.11	4.93	.33	.38	.40
A14	6.10	5.59	5.40	.30	.33	.34
A15	6.63	6.08	5.87	.29	.30	.31
A16	7.16	6.56	6.34	.28	.29	.30
A17	7.69	7.05	6.81	.27	.28	.29
A18	8.22	7.54	7.28	.27	.28	.28
A19	5.02	4.60	4.44	.31	.34	.36
A20	5.65	5.18	5.01	.28	.30	.30
A21	6.29	5.76	5.57	.27	.28	.28
A22	6.93	6.35	6.13	.26	.27	.27
A23	7.96	6.93	6.69	.26	.26	.27
A24	8.20	7.51	7.25	.26	.26	.26
A25	4.65	4.29	4.14	.29	.32	.34
A26	5.42	4.97	4.80	.27	.28	.28
A27	6.16	5.64	5.45	.26	.26	.27
A28	6.90	6.32	6.11	.26	.26	.26
A29	7.64	7.00	6.76	.25	.26	.26
A30	8.38	7.68	7.42	.25	.25	.26

Table 26. Cost per Vehicle per Year Versus Total Waiting Time for Biannual Inspection

Configuration	Cost per Vehicle per Year 1975	1980	1985	Total Waiting Time (Hrs.) 1975	1980	1985
B 1	$4.93	$4.51	$4.36	.56	.70	.78
B 2	5.25	4.81	4.64	.50	.59	.64
B 3	5.57	5.10	4.93	.46	.53	.56
B 4	5.89	5.39	5.21	.43	.48	.51
B 5	6.21	5.69	5.49	.41	.45	.47
B 6	6.52	5.98	5.78	.39	.43	.44
B 7	3.30	3.02	2.92	.39	.46	.51
B 8	3.72	3.41	3.30	.34	.37	.39
B 9	4.15	3.80	3.67	.31	.33	.34
B10	4.57	4.19	4.10	.30	.31	.32
B11	5.00	4.58	4.43	.29	.30	.30
B12	5.42	4.97	4.80	.28	.29	.29
B13	2.74	2.52	2.43	.34	.39	.42
B14	3.28	3.00	2.90	.29	.31	.32
B15	3.81	3.49	3.37	.27	.28	.29
B16	4.34	3.97	3.89	.27	.27	.27
B17	4.87	4.45	4.31	.26	.27	.27
B18	5.40	4.94	4.78	.26	.26	.26
B19	2.51	2.30	2.22	.31	.34	.36
B20	3.15	2.88	2.78	.27	.28	.28
B21	3.78	3.47	3.35	.26	.26	.27
B22	4.42	4.05	3.91	.26	.26	.26
B23	5.05	4.63	4.47	.25	.26	.26
B24	5.69	5.21	5.04	.25	.25	.25
B25	2.28	2.09	2.02	.30	.33	.36
B26	3.02	2.77	2.77	.26	.27	.27
B27	3.76	3.45	3.33	.26	.26	.26
B28	4.50	4.13	3.99	.25	.25	.25
B29	5.24	4.80	4.64	.25	.25	.25
B30	5.98	5.48	5.30	.25	.25	.25

If the number of sites available for inspection facilities are limited for the Atlanta Metropolitan Area, biannual inspection may be a preferred alternative to annual inspection.

Total Equivalent Annual Cost. Total equivalent annual cost values obtained in this investigation decrease as the number of lanes per facility increase. This is reasonable since, for example, it is more expensive to have an inspection system with one cashier per one lane facility as opposed to one cashier to serve for a five lane facility.

Tables 23 and 24 indicate the importance of the costs of fixed and variable labor upon total equivalent annual costs. For all one lane facility configurations, fixed labor costs (such as the cost of a supervisor for a facility) are higher than the variable labor costs (cost of personnel who actually perform the vehicle inspection). Fixed labor costs, however, are lower than variable labor costs for all five lane facility configurations.

Following annual labor costs expenditures, recovery of the initial investment is the next most expensive component of total equivalent annual cost. As explained in Chapter V, an 8 per cent interest rate on borrowed money was chosen. Fixed operating costs for lights and for heating the facilities were found to be the least expensive annual expenditure.

Cost per Vehicle per Year. Since the cost per vehicle per year is calculated by dividing the total equivalent annual cost per year by the number of vehicles to be inspected, the cost per vehicle varies directly with total equivalent annual costs. Therefore, the cost of annual fixed and variable labor is an important factor in determining the cost per vehicle per year.

Tables 25 and 26 give the range of cost values for each configuration over the time span of the study. Since a vehicle would be inspected every two years on a biannual inspection, the cost given for biannual inspection in Table 26 is approximately one-half the total value the vehicle owner would be charged for an inspection every two years. The values in Table 26 are reported on a per-year basis to make them comparable with annual inspection.

Performance of Inspection System Configurations

For this investigation, total waiting time per vehicle is the measure of performance of an inspection system configuration. Total waiting time per vehicle is calculated by adding the time a customer waits in line outside the inspection facility plus the time a customer is being serviced. A service time of 15 minutes is allowed per vehicle [7]. This would include time for the short cycle vehicle inspection test, the necessary paperwork, and the time for instructions for obtaining corrective procedures and for providing proper maintenance of defective pollution control devices.

Performance of an inspection system configuration, as measured by total waiting time per vehicle, improves as the size of the facilities (i.e., number of lanes per facility) increases. For a given number of vehicles to be inspected, the probability of having to wait is greater if all one lane facilities, as opposed to all five lane facilities, comprise the inspection system. Tables 25 and 26 give the range of total waiting time values obtained for each configuration over the time span of the study.

Summary of Cost and Effectiveness Measurements

Three inspection system configurations for annual inspection and three inspection system configurations for biannual inspection are chosen out of the 60 configurations (given in Tables 21 through 26) to illustrate cost-effectiveness results. Table 27 is a summary of the measurements of cost, performance and effectiveness for each of the six configurations. The six configurations are of comparable utilization (i.e., approximately 72-82 per cent over the time span of the study).

The cost per vehicle per year (1980) varies from \$4.29 to \$6.11 for annual inspection; for biannual inspection, the cost per vehicle per year (1980) varies from \$2.04 to \$3.02. The more expensive cost per vehicle values are for inspection configurations with less lanes per facility.

The total waiting time per vehicle ranges from approximately 15 minutes (.25 hours) to 30 minutes (.50 hours). Less waiting time is associated with the inspection system configurations having more lanes per facility. The reason for the variance in waiting time is explained in Chapter V.

Effectiveness of annual and biannual state inspection is measured in terms of total pollution levels, reductions and percentage of potential reductions achieved over the time span of the investigation. The effectiveness of state inspection is independent of the specific

Table 27. Summary of Measurements of Cost, Performance and Effectiveness for Annual Versus Biannual Inspection

Configuration*	Number of Facilities Required	Cost per Vehicle per Year			Total Waiting Time (Hrs.) per Vehicle			Effectiveness (1975 thru 1985)		Percent of Potential Reductions Achieved	
		1975	1980	1985	1975	1980	1985	Total Emissions with Inspection (Tons × 10^6)	Total Reductions with Inspection (Tons × 10^6)	1975	1985
A 7	89	\$6.66	\$6.11	\$5.90	.39	.45	.49	CO = 2.440	CO = .498	CO = 82	CO = 80
A13	59	5.57	5.11	4.93	.33	.38	.40	HC = .241	HC = .052	HC = 68	HC = 82
A25	35	4.65	4.29	4.14	.29	.32	.34	NOX = .247	NOX = .029	NOX = 24	NOX = 82
B 7	44	3.30	3.02	2.92	.39	.46	.51	CO = 2.525	CO = .413	CO = 41	CO = 71
B13	29	2.74	2.52	2.43	.34	.39	.42	HC = .250	HC = .043	HC = 34	HC = 73
B25	17	2.28	2.04	2.02	.30	.33	.36	NOX = .250	NOX = .026	NOX = 12	NOX = 73

*"A" denotes an annual inspection system configuration.
"B" denotes a biannual inspection system configuration.

configuration chosen. For example, 89 two lane facilities will be equally as effective as 35 five lane facilities in reducing automotive air pollution since all vehicles can be inspected by either configuration. Year-by-year measurements of effectiveness are given in Tables 17, 18, and 19. On the basis of cost and effectiveness, biannual inspection compares favorably with annual inspection. In the initial years of inspection, the effectiveness of state inspection to reduce nitrogen oxides is questionable.

Cost and Effectiveness Sensitivity Analysis

The general aim of this section is to test the sensitivity of inspection cost and effectiveness results to changes in three variables. The three variables are:

1. The rate of deterioration of control devices.
2. The inspection facility staff requirements.
3. The service time required per vehicle at the inspection facility.

The rate of deterioration of control devices was chosen to be tested because presently deterioration rates of future control devices are unknown. Only the proposed Federal emission standards for future automobiles are specified.

The sensitivity of the total costs of inspection to (1) facility staff requirements and (2) the service time required per vehicle are tested because fixed and variable labor cost were identified to be major expenditure components of total equivalent annual cost (Tables 23 and 24 illustrate the importance of annual labor cost). By investigating these two factors, it is hoped to identify promising inspection system design approaches to reduce the cost of state inspection.

Sensitivity of Effectiveness to Rate of Deterioration

The following equations for the deterioration of carbon monoxide control devices are representative of equations used to calculate pollutant emissions:

$$(1)\quad D_{t1} = (.0048\ CCMIS+1.08)\left(1-e^{-CCMIS/2}\right)$$

$$(2)\quad D_{t2} = (.0766\ CCMIS+.934)\left(1-e^{-CCMIS/2}\right)$$

where,

D_t = Deterioration value associated with a vehicle after a given number of cumulative vehicle miles.

CCMIS = Cumulative vehicle miles in thousands ($CCMIS \geq 4$).

The first equation is assumed to be representative of 1968-1975 model year vehicles; the second equation is assumed to be representative of vehicles manufactured after 1975 (Chapter IV gives a discussion of deterioration equations). A rate of deterioration is associated with each of the above equations and could be found by differentiating the equations. Because the mathematical expression describing the rate of deterioration could not be readily incorporated into the computer model, an approximation was required. To approximate higher rates of deterioration for equations (1) and (2), the CCMIS term in each equation is multiplied by $\left(1 + \frac{P}{100}\right)$, where P is the rate of increase, expressed as a percentage. For example, a 30 per cent increase in the rate of deterioration of D_{t1} would be approximated as follows:

$$D_{t1} = \left(.0048(1.3)CCMIS+1.08\right)\left(1-e^{-(1.3)CCMIS/2}\right)$$

In this study a 50 per cent increase in the rate of deterioration is investigated. Tables 28 and 29 are presented to illustrate that the approximation of the increase in the rate of deterioration is good for vehicles that are more than a year old. For 1968-1975 model year vehicles, the approximation procedure will underestimate the rate of deterioration in the first year of the vehicle's life by 18 per cent. For 1976 model year vehicles and later, the approximation procedure will overestimate the rate of deterioration in the first year by 4 per cent.

Tables 30 and 31 indicate that a 50 per cent increase in the deterioration rate of control devices does not substantially change the effectiveness of annual versus biannual inspection. Apparently, other factors (perhaps vehicles initially achieving the future proposed Federal standards) are more important than the rate of deterioration of control devices. Also if pollution control devices in the future exhibit deterioration as described by a quadratic or another type of deterioration equation, results may differ.

Sensitivity of TEAC to Decreased Staff Requirements

The two personnel who would probably be considered to be more expendable if cutbacks in costs were required would be the janitor and the trainee assigned to each facility. For this reason, it was of interest to see the net economic result of having no janitors or trainees. Table 32 gives an 8 to 14 per cent change in total equivalent annual cost for the reduction in facility staff requirements. Because of computer time and other investigation constraints, other strategies such as requiring one mechanic to handle more than one lane were not considered.

Sensitivity of TEAC to Increased Service Time

In this investigation 15 minutes is considered to be the average service time per vehicle. This value was chosen to allow ample time for the actual vehicle inspection, paperwork and instructions to the vehicle owner concerning proper maintenance and/or replacement of automotive pollution control devices. Also, 15 minutes would allow the inspection facility personnel time to identify minor malfunctions, such as loose spark plug wires, which if corrected at the inspection facility might help the vehicle to pass the inspection test. The actual exhaust pollutant emission test would probably require only 1-3 minutes depending upon the test procedure.

If an improved scheduling procedure or a more automated inspection system could be devised, labor costs could be reduced. For this reason, the sensitivity of total equivalent annual cost to a change in service time from 15 minutes to 10 minutes was investigated. Table 33 gives investigation results. The percentage change in TEAC is approximately equal to the percentage change in service time. Also, the number of facilities required is less with a 10 minute service time as opposed to a 15 minute service time.

Table 28. Verification of the Method Used to Approximate a 50 Per Cent Increase in the Rate of Deterioration of Control Devices for 1968-1975 Model Year Vehicles

Vehicle Age (Years)	Miles Driven During Year (Thousands)	CCMIS[a] (Thousands)	D_{t1}[b]	(1) ΔD_{t1} / ΔCCMIS	D'_{t1}[c]	(2) $\Delta D'_{t1}$ / ΔCCMIS	$\frac{(2)}{(1)}$	Error (%)
		4.0	1.00000	-	1.00000	-	-	-
0-1	13.2	13.2	1.14181	.01541	1.17445	.01896	1.23	-18
1-2	12.0	25.2	1.20096	.00493	1.26144	.00725	1.47	- 2
2-3	11.0	36.2	1.25376	.00480	1.34064	.00720	1.50	0
3-4	9.6	45.8	1.29984	.00480	1.40976	.00720	1.50	0
4-5	9.4	55.2	1.34496	.00480	1.47744	.00720	1.50	0
5-6	8.7	63.9	1.38672	.00480	1.54008	.00720	1.50	0
6-7	8.6	72.5	1.42800	.00480	1.60200	.00720	1.50	0
7-8	8.1	80.6	1.46688	.00480	1.66032	.00720	1.50	0
8-9	7.3	87.9	1.50192	.00480	1.71288	.00720	1.50	0
9-10	7.0	94.9	1.53552	.00480	1.76328	.00720	1.50	0
10-11	5.7	100.6	1.56288	.00480	1.80432	.00720	1.50	0
11-12	4.9	105.5	1.58640	.00480	1.83960	.00720	1.50	0
≥ 12	4.3	109.8	1.60704	.00480	1.87056	.00720	1.50	0

[a] Cumulative vehicle mileage.

[b] $D_{t1} = (.0048\text{CCMIS}+1.08)\left[1-e^{-\text{CCMIS}/2}\right].$

[c] $D'_{t1} = \left[.007(\text{CCMIS})+1.08\right]\left[1-e^{-1.5\text{CCMIS}/2}\right].$

Table 29. Verification of the Method Used to Approximate a 50 Per Cent Increase in the Rate of Deterioration of Control Devices for Post-1975 Vehicles

Vehicle Age (Years)	Miles Driven During Year (Thousands)	CCMIS[a] (Thousands)	D_{t_2}[b]	(1) $\frac{\Delta D_{t_2}}{\Delta CCMIS}$	D'_{t_2}[c]	(2) $\frac{\Delta D'_{t2}}{\Delta CCMIS}$	$\frac{(2)}{(1)}$	Errors (%)
		4.0	1.00000	-	1.00000	-	-	-
0-1	13.2	13.2	1.94247	.10244	2.45068	.15768	1.54	+4
1-2	12.0	25.2	2.86432	.07682	3.82948	.11490	1.50	0
2-3	11.0	36.2	3.70692	.07660	5.09338	.11490	1.50	0
3-4	9.6	45.8	4.44228	.07660	6.19642	.11490	1.50	0
4-5	9.4	55.2	5.16232	.07660	7.27648	.11490	1.50	0
5-6	8.7	63.9	5.82874	.07660	8.27611	.11490	1.50	0
6-7	8.6	72.5	6.48750	.07660	9.26425	.11490	1.50	0
7-8	8.1	80.6	7.10796	.07660	10.19494	.11490	1.50	0
8-9	7.3	87.9	7.66714	.07660	11.03371	.11490	1.50	0
9-10	7.6	94.9	8.20334	.07660	11.83801	.11490	1.50	0
10-11	5.7	100.6	8.63996	.07660	12.49294	.11490	1.50	0
11-12	4.9	105.5	9.06530	.07660	13.05595	.11490	1.50	0
≥ 12	4.3	109.8	9.34468	.07660	13.55002	.11490	1.50	0

[a]Cumulative Vehicle Mileage.

[b]$D_{t_2} = (.0766CCMIS+.934)\left(1-e^{-CCMIS/2}\right).$

[c]$D'_{t_2} = (.1149CCMIS+.934)\left(1-e^{-1.5CCMIS/2}\right).$

Table 30. Effect of Typical vs. High Deterioration Rates on Total Estimated Pollutant Emissions (1975-1985)

Pollutant	Emissions (Tons) Without State Inspection: Typical Deterioration (Tons)	High Deterioration* (Tons)	Percentage Increase
CO	2,938,564	3,379,898	15
HC	293,308	329,824	12
OX	276,989	305,141	10
	Emissions (Tons) With Biannual Inspection		
CO	2,525,104	2,654,052	5
HC	250,112	258,594	3
OX	250,260	258,425	3
	Emissions (Tons) with Annual Inspection		
CO	2,440,186	2,524,275	3
HC	241,358	245,926	2
OX	247,834	250,354	1

*High deterioration is defined to be a rate approximately 50 per cent greater than anticipated typical deterioration rates.

Table 31. Comparison of Total Estimated Pollutant Emission Reductions Achieved with Annual vs. Biannual Inspection (1975-1985)

Pollutant	Total Emission Reductions Achieved (Assuming High* Deterioration Rates) Biannual Inspection (Tons)	Annual Inspection (Tons)	Maximum Possible Reductions Achievable (Tons)
CO	725,846	855,623	1,130,084
HC	71,230	83,898	112,342
OX	46,716	54,787	82,542

*High deterioration is defined to be a rate approximately 50 per cent greater than anticipated typical deterioration rates.

Table 32. Sensitivity of TEAC to Changes in Facility Staff Requirements

Configuration	TEAC *before* Reduction in Staff Requirements	TEAC[a] *after* Reduction in Staff Requirements	Percentage Change in TEAC
A 7	$5,659,789	$4,855,229	-14
A13	4,733,550	4,200,190	-11
A25	3,974,687	3,658,287	- 8
B 7	2,799,812	2,402,052	-14
B13	2,329,246	2,067,086	-11
B25	1,934,921	1,781,241	- 8

[a]Reductions occur by having no janitor or trainee.

Table 33. Sensitivity of TEAC to Changes in Service Time

	Service Time = 15 Minutes			Service Time = 10 Minutes			
	Number of Facilities Required	Lanes per Facility	TEAC	Number of Facilities Required	Lanes per Facility	TEAC	Percentage Change in TEAC
Annual Inspection	89	2	$5,659,789	59	2	$3,854,851	-31
	59	3	4,733,550	39	3	3,232,394	-32
	35	5	3,974,687	23	5	2,716,557	-32
Biannual Inspection	44	2	2,799,812	29	2	1,897,343	-32
	29	3	2,329,246	19	3	1,578,668	-32
	17	5	1,934,912	11	5	1,305,856	-33

NOTE: Utilization of facilities is approximately 72-82 per cent.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this research, as stated in Chapter I, was to design and evaluate a system to inspect exhaust gas emission control devices. To accomplish the objective, individual elements of the system are analyzed and then the elemental costs or contributions to emission reductions are aggregated.

As a result of this investigation, additional insights to the problem of automotive emission control were forthcoming. New areas for investigation became evident and a number of important conclusions resulted.

Conclusions

Design of Inspection Systems

The frequency of inspection should be considered by local pollution control agencies. Biannual inspection, as opposed to annual inspection, requires less investment in facilities and equipment. Also, the number of inspection sites required is less with biannual inspection. On the basis of total pollutant emissions and reductions, a biannual inspection frequency compares favorably with an annual inspection frequency.

The number of inspection lanes per facility is an important design consideration. For a given number of vehicles to be inspected and a given total number of inspection lanes, the expected waiting time per vehicle decreases as the number of lanes per facility increases.

The time required to inspect a vehicle is important. Through improved scheduling to ensure that vehicles arrive at the inspection facilities in a uniform manner, as opposed to arriving at the end of the month, plus a faster service time per vehicle, the number of facilities required can be reduced.

Since automotive emission control systems are becoming more sophisticated, it is reasonable to conclude that testing procedures will have to be improved to detect malfunctions. Based upon a review of the literature, a short cycle type of inspection procedure offers (in terms of diagnostic capability) the most acceptable testing method. Therefore, projections of the test equipment needs for an inspection should include the cost of auxiliary equipment for a short cycle test.

Evaluation of Inspection Systems

The approach taken in this investigation offered an excellent method for evaluating policy decisions which will be required by state pollution control agencies. Specifically, the impact of various state standards upon total emissions and reductions could be evaluated.

Effectiveness of Inspection Systems. The effectiveness of state inspection to reduce carbon monoxide and hydrocarbons pollutant emissions will decrease from 1975 to 1978, then increase from 1979 to 1985. The decrease in effectiveness for the initial years of inspection is due to the large pollutant reductions the first year of inspection; and then a decreasing quantity of pollutant reductions is achieved in 1976, 1977, and 1978. The increase in effectiveness is attributed to maintaining vehicle pollutant emission rates at a desired level while the pollutant emission rates assuming no state inspection are not controlled. Therefore, with an increasing vehicle population and deteriorating exhaust pollutant control devices, the numerical difference between the total emissions without state inspection and the emissions with state inspection increases from 1978 to 1985.

State inspection to reduce automotive nitrogen oxide emissions is not effective until 1978. Control devices have not deteriorated to a level where state inspection can become effective. After 1978, the effectiveness of state inspection to control nitrogen oxides tends to increase.

Increasing the rate of deterioration of exhaust control devices increased the reductions achieved by both annual and biannual inspection. Considering the tradeoff in pollutant emission reductions and other factors such as cost of inspection, biannual inspection compares favorably to annual inspection even at the higher deterioration rates for pollution control devices.

Cost of Inspection Systems. Fixed and variable labor costs were found to be the most important operating expenditures for an inspection system. By decreasing two personnel (a janitor plus a trainee) at each facility, an 8 to 14 per cent reduction in total equivalent annual cost was obtained. Also, all labor costs were a high percentage of total equivalent annual costs.

Another method which was found to be effective in reducing total equivalent annual cost was increasing the vehicle service time at each facility. By employing this approach, a smaller number of facilities were required and also less personnel were required.

Recommendations

The decision to implement an inspection system to reduce automotive exhaust pollutant emissions will be made based upon several types of information. The cost-effectiveness results given in this investigation provide one type of information which will assist state pollution control agencies in making a final decision.

To promote further research and to improve the approach taken in this investigation, the following recommendations are given:

1. The possibility of incorporating safety inspection into the air pollution inspection system should be investigated. Since only the cost of safety inspection equipment plus additional cost for building construction would be required, this would represent only a small incremental cost addition to the proposed air pollution inspection system.

2. An investigation should be initiated to determine the cost to the public associated with time and expense required in driving to and from the inspection facilities. Also, the cost of waiting at the inspection facility should be considered.

3. The advantages and disadvantages of a state or a privately owned vehicle inspection system should be investigated.

4. Air quality data should be collected in a manner to verify or refute that the model used in this investigation is correctly

predicting an overall decrease in the level of automotive carbon monoxide, hydrocarbons and nitrogen oxide pollutants without state inspection.

5. Data should be collected to quantify (1) vehicle emission rates before inspection, (2) vehicle emission rates after inspection and correction of defective devices, and (3) rate of deterioration of control devices after they have been corrected. Is deterioration of control devices gradual or does deterioration occur rapidly after corrections have been made?

6. Other systems for inspecting vehicles should be investigated. For instance, if durable mobile inspection facilities could be developed, states might consider utilizing shopping center parking lots for inspection sites.

7. Further work should be initiated to determine if existing test equipment is capable of accurately measuring low concentrations of exhaust pollutants anticipated for future model year vehicles. If more accuracy is required, test equipment could become more expensive and, therefore, the overall cost of inspection will increase.

8. Since pre-1968 model year vehicles have no exhaust pollution control devices, an obvious pollution control gap exists between pre-1968 vehicles and other vehicles. More data should be collected to identify the overall importance of pre-1968 vehicles to the total automotive pollution problem. Perhaps, installation of pollution control devices for pre-1968 vehicles could be justified as a preferred alternative for controlling this group of vehicles.

9. Since automotive emissions are important sources of hydrocarbons and nitrogen oxides in many metropolitan areas, perhaps more emphasis should be placed upon developing stringent state automotive pollution standards for these pollutants as opposed to carbon monoxide standards. Pollutant control priorities should be established to agree with air quality needs of each state or the needs of individual cities within each state.

APPENDICES

APPENDIX A

FLOW DIAGRAMS OF POLLUTION CONTROL MODEL (PCM)

Four flow diagrams are given on the following pages to illustrate how the inputs to the Pollution Control Model (PCM) are utilized to make calculations required to obtain measures of inspection system effectiveness.

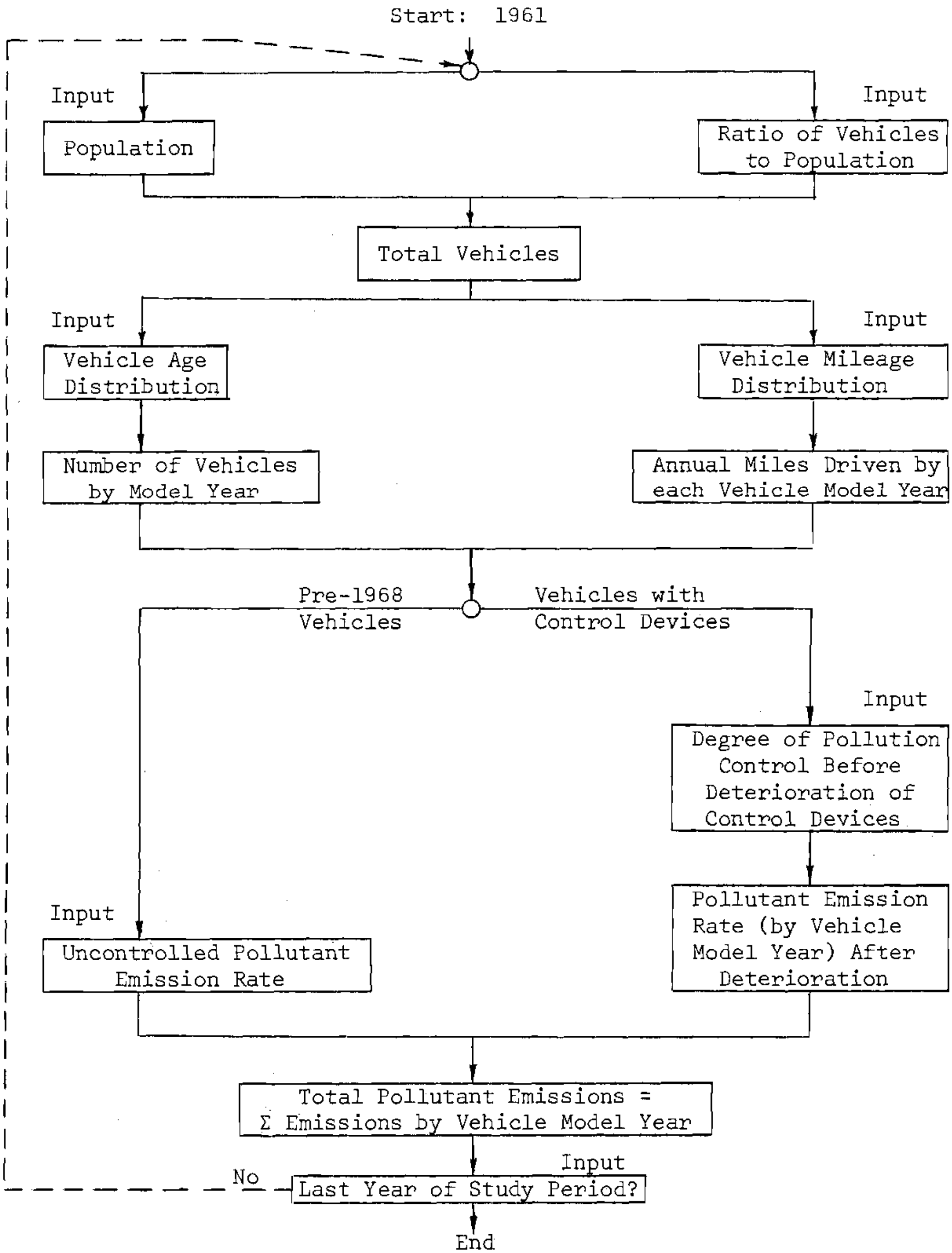


Figure 23. Flow Diagram of Carbon Monoxide Upper Limit Calculations

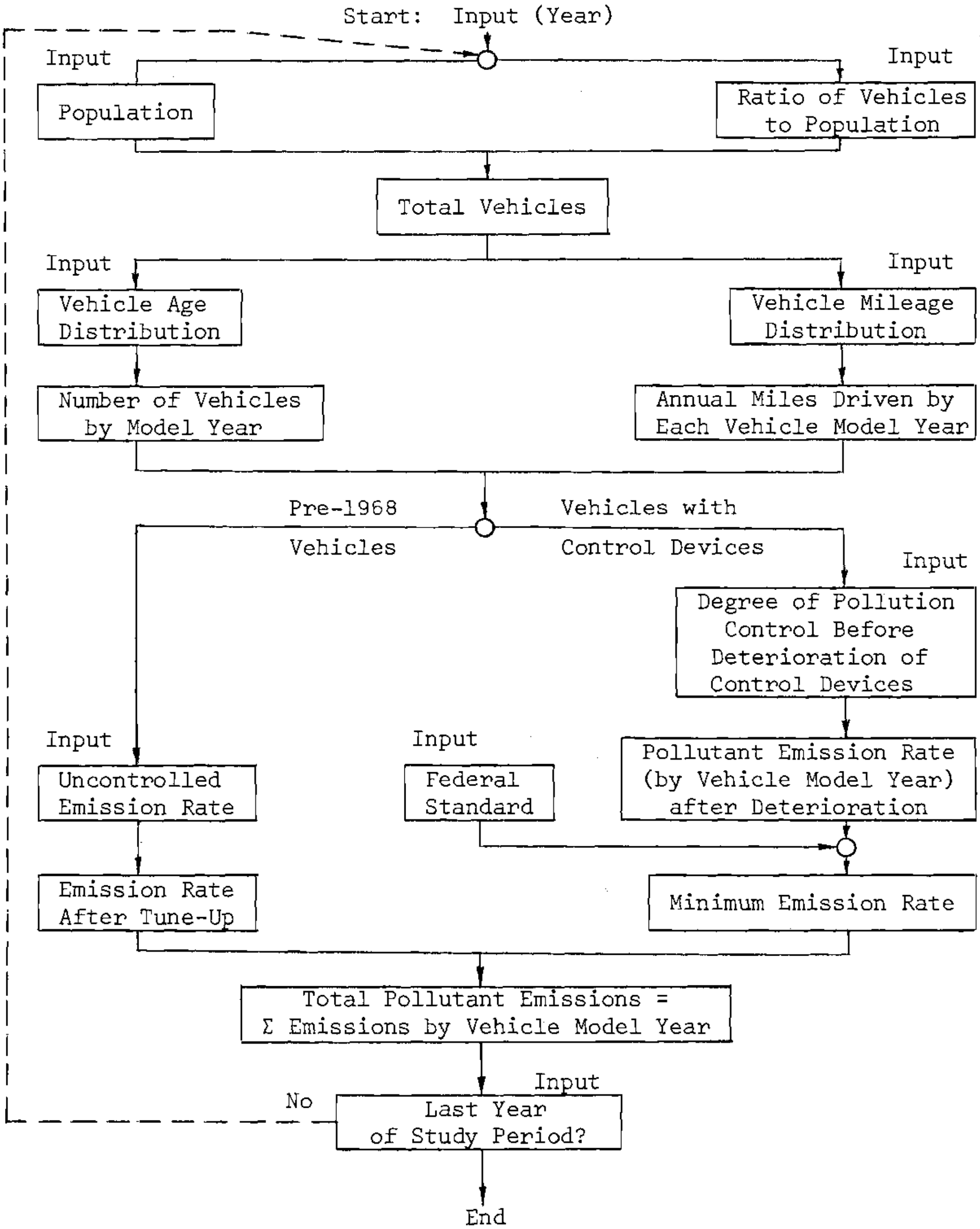


Figure 24. Flow Diagram of Carbon Monoxide Lower Limit Calculations

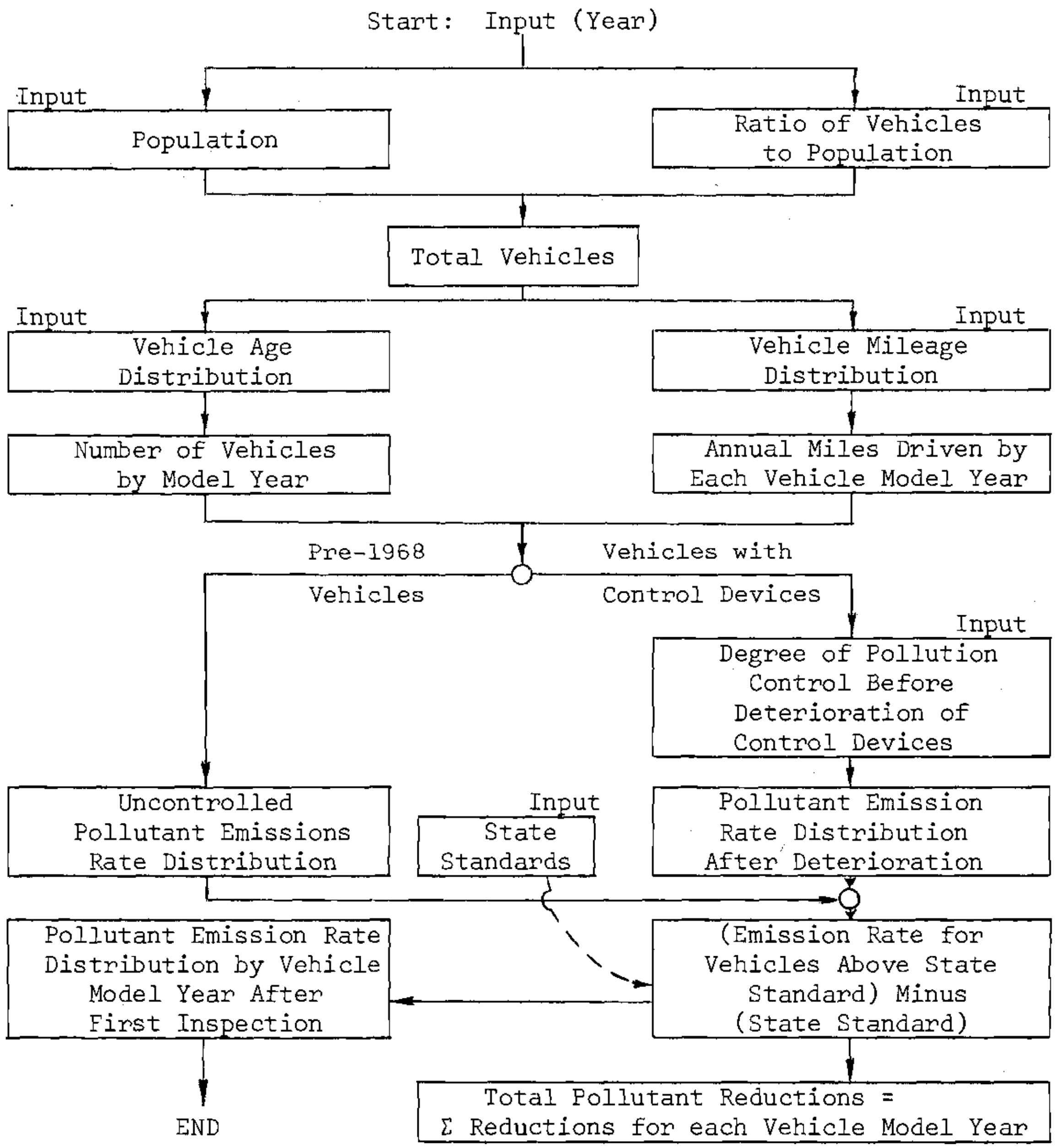


Figure 25. Flow Diagram of First Year Pollutant Reduction Calculations

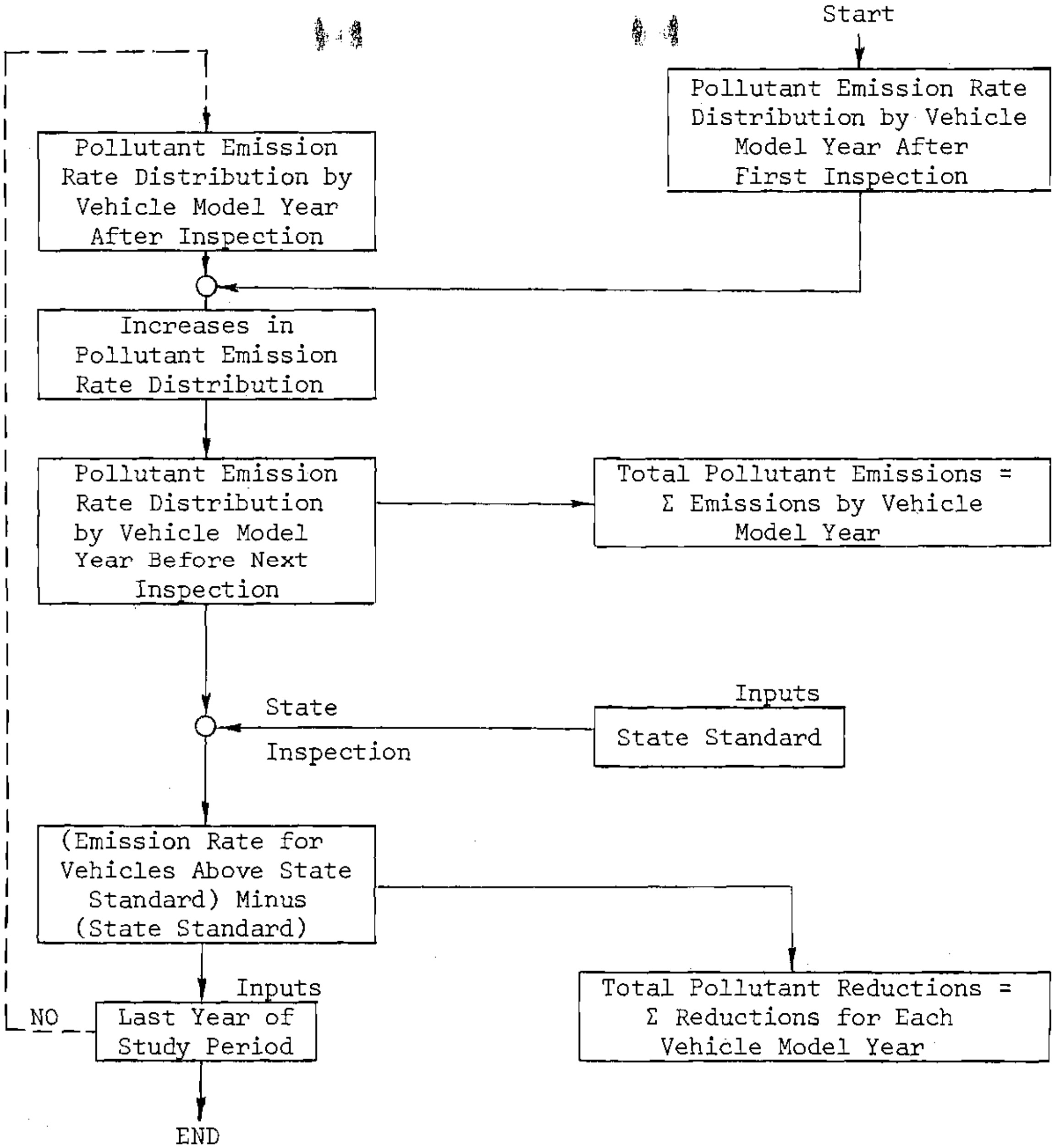


Figure 26. Flow Diagram of Calculations for Carbon Monoxide Total Pollutant Emissions and Total Pollutant Reductions with State Inspection

APPENDIX B

POPULATION ESTIMATES, ATLANTA METROPOLITAN AREA

(1961-1985)

Year	Population (Number of Persons)	Year	Population (Number of Persons)
1961	1,050,090	1974	1,537,353
1962	1,083,172	1975	1,572,900
1963	1,116,254	1976	1,621,849
1964	1,149,336	1977	1,670,798
1965	1,182,600	1978	1,719,747
1966	1,224,112	1979	1,768,696
1967	1,265,624	1980	1,817,700
1968	1,317,136	1981	1,871,367
1969	1,358,648	1982	1,925,034
1970	1,390,164	1983	1,978,701
1971	1,426,711	1984	2,032,368
1972	1,463,258	1985	2,086,000
1973	1,500,805		

[Source: References 31 and 32.]

APPENDIX C

EMISSION DATA FOR HYDROCARBONS AND NITROGEN OXIDES

In Chapter IV, emission data was given for carbon monoxide to illustrate the details of the investigation approach. The following Tables give emission data for the other two pollutants considered in this investigation.

Table 34. Hydrocarbon Distribution for Pre-1968 Vehicles

Percentage of Total Pre-1968 Vehicles	Exhaust Hydrocarbon Emissions
0-10	6.4 gms/mile
10-20	7.3
20-30	9.1
30-40	10.0
40-50	11.5
50-60	12.8
60-70	13.7
70-80	16.4
80-90	18.2
90-100	25.5

Table 35. Hydrocarbon Base Level Emissions, Federal Exhaust Standards, and State Standards (Representative of 1972 CVS Test Procedures)

Year	Base Level Emissions	Federal Exhaust Standards	State Standards
Pre-1968	(Average Uncontrolled Rate = 13.10)		12.80
1968	5.60	6.10	6.71
1969	5.60	6.10	6.71
1970	3.50	3.80	4.18
1971	3.50	3.80	4.18
1972	3.10	3.40	3.73
1973	3.10	3.40	3.73
1974	3.10	3.40	3.73
1975	3.10	3.40	3.73
1976	.42	.46	.51
1977	.42	.46	.51
1978	.42	.46	.51
1979	.42	.46	.51
1980	.42	.46	.51
1981	.42	.46	.51
1982	.42	.46	.51
1983	.42	.46	.51
1984	.42	.46	.51
1985	.42	.46	.51

NOTE: All pollutant emission values are in grams per mile.

Table 36. Nitrogen Oxide Base Level Emissions, Federal Exhaust Standards, and State Standards (Representative of 1972 CVS Test Procedures)

Year	Base Level Emissions	Federal Exhaust Standards	State Standards
Pre-1968	(Average Uncontrolled Rate = 6.40)		-
1968	(Average Uncontrolled Rate = 7.10)		-
1969	(Average Uncontrolled Rate = 7.10)		-
1970	(Average Uncontrolled Rate = 5.50)		-
1971	(Average Uncontrolled Rate = 5.50)		-
1972	(Average Uncontrolled Rate = 4.40)		-
1973	2.70	3.00	3.30
1974	2.70	3.00	3.30
1975	2.70	3.00	3.30
1976	.50	.60	.66
1977	.50	.60	.66
1978	.50	.60	.66
1979	.50	.60	.66
1980	.50	.60	.66
1981	.50	.60	.66
1982	.50	.60	.66
1983	.50	.60	.66
1984	.50	.60	.66
1985	.50	.60	.66

NOTE: All pollutant emission values are in grams per mile.

APPENDIX D

DETERIORATION EQUATIONS FOR HYDROCARBON AUTOMOTIVE POLLUTANT CONTROL SYSTEMS

Two hydrocarbon deterioration equations are utilized in the Pollution Control Model, which was explained in Chapter IV. The two equations are:

1. $D = (.0024\ CCMIS+1.09)\left[1-e^{(CCMIS/2)}\right]$

2. $D = (.0706\ CCMIS+.74)\left[1-e^{(-CCMIS/2)}\right]$

where,

D = Deterioration value.

CCMIS = Cumulative vehicle miles in thousands ($CCMIS \geq 4$).

The first equation applies to 1968-1975 model year vehicles. The second equation applies to 1976 and later model year vehicles.

The equation applicable to 1968-1975 model year vehicle was derived based upon information received from California [25]. The second equation was derived by assuming 1976 and later model year vehicles' control systems would deteriorate to the 1973 Federal standard over the lifetime (109,800 miles) of the vehicle.

APPENDIX E

DETERIORATION EQUATIONS FOR NITROGEN OXIDE AUTOMOTIVE POLLUTANT CONTROL SYSTEMS

Two nitrogen oxide deterioration equations are utilized in the Pollution Control Model, which was explained in Chapter IV. The two equations are:

$$1.\quad D = (.0044\ CCMIS+1.15)\left[1-e^{(-CCMIS/2)}\right]$$

$$2.\quad D = (.045\ CCMIS+1.05)\left[1-e^{\ -CCMIS/2)}\right]$$

where,

D = Deterioration value.

CCMIS = Cumulative vehicle miles in thousands ($CCMIS \geq 4$).

The first equation applies to 1973-1975 model year vehicles. The second equation applies to 1976 and later model year vehicles.

The equation applicable to 1973-1975 model year vehicles was derived by assuming control devices on these vehicles would deteriorate to 4.4 grams per mile. The 4.4 grams per mile is the average uncontrolled emission rate assumed for 1972 model year vehicles (see Appendix C). The equation applicable to post-1975 model year vehicles was derived by assuming control devices would deteriorate to the 1973 Federal standard over the lifetime (109,800 miles) of the vehicle.

APPENDIX F

FLOW DIAGRAM OF COST MODEL (CM)

As explained in Chapter V, the Cost Model is used to make calculations of costs and waiting time for various inspection system configurations. Figure 27 illustrates how inputs are used to calculate the required costs and waiting time data.

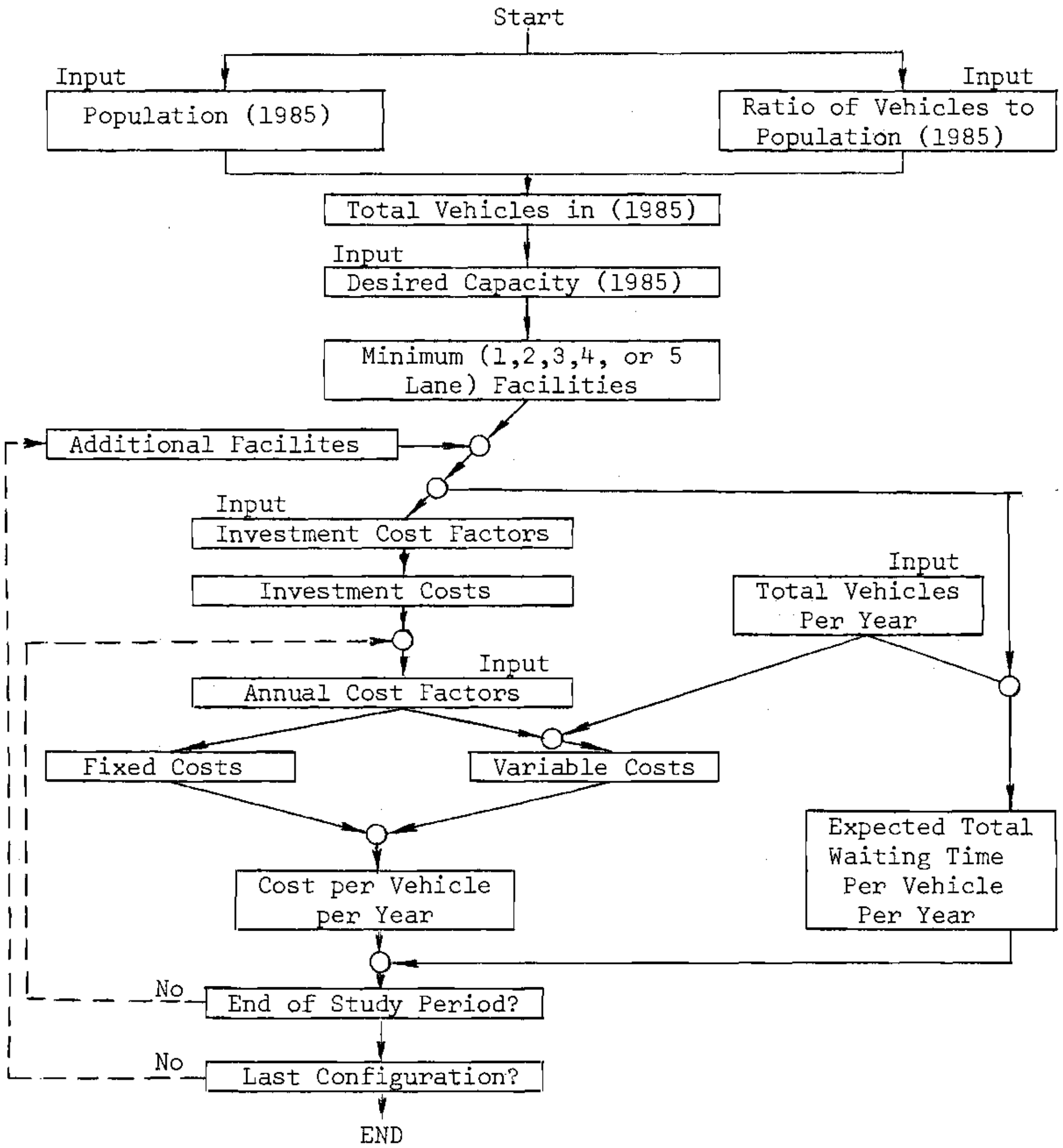


Figure 27. Flow Diagram of Cost Model Calculations

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